struc'tur'al TECHNOLOGIES

Strengthening with FRP Composite

Engineering Principles, Guidelines and Case Studies

Tarek Alkhrdaji, PhD, PE
Vice President – Engineering Services

Deterioration (corrosion)

Prestressed Beam Failure

Environmental

Environmental

Renovation (Adaptive Reuse)

Design, Construction…Error

Seismic Upgrade

Failed Double – T-Stem

Design, Construction…Error

structural TECHNOLOGIES

Strengthening - Conventional Options

- Section enlargement

- Span shortening

- External Post-Tensioning

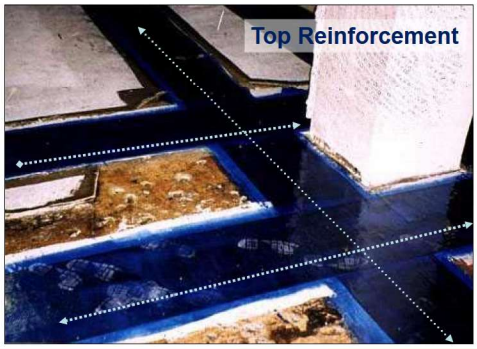
- Steel Plate Bonding

structural TECHNOLOGIES

Flexural Strengthening

structural TECHNOLOGIES

Flexural Strengthening



Slab Openings – Flexural Strengthening

New exhaust duct opening

Beam Shear Upgrade

Column Strengthening

structural TECHNOLOGIES

Lateral Resisting System Upgrade

- New 23 Story Hi-rise Building

structural TECHNOLOGIES

Underground Pipelines

structural TECHNOLOGIES

Surface Prep – CRITICAL!

Methods:

- Abrasive Blasting
- Dustless Grinding & Vacuum
- Water Blast & Dry

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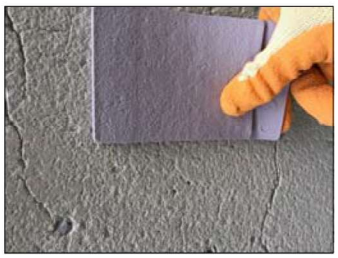
Surface Prep – CRITICAL!

Desired Surface Profile: CSP-3



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FRP Installation

structural TECHNOLOGIES

Completed Bridge Pier - FRP Strengthening

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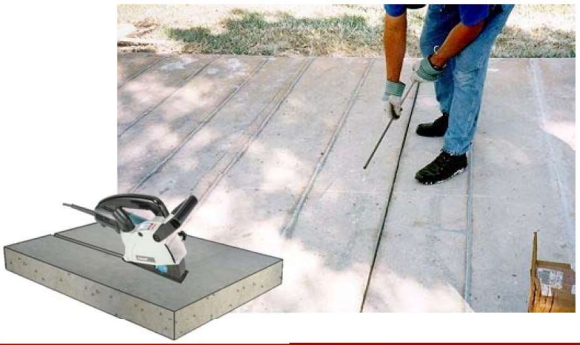
Near-Surface Mounted (NSM) FRP Bars

structural TECHNOLOGIES

Near Surface Mounted (NSM) FRP



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FRP Rods

Carbon:
#3 (T10)
#4 (T12)

Glass:
All standard sizes

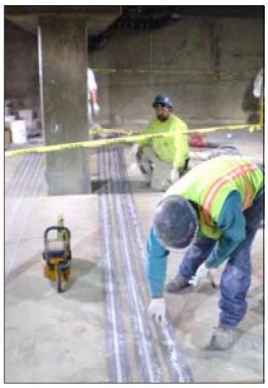
FRP Rods

Typical groove size
¾" (18mm) X ¾" (18mm)

Confirm rebar depth > ¾" (18mm) with GPR or other!

FRP Rods

- Fill and strike off with margin trowel and pull tape



FRP Rods – Finished Surface


One way


Two way

structural TECHNOLOGIES

structural TECHNOLOGIES

V-Wrap FRP Systems

V-Wrap™ FRP Systems


Carbon Fabric


Glass Fabric


Carbon Rods


Epoxy


Carbon Plate


Anchors

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V-Wrap™ FRP Systems

Code Approved Products (ICC-ESR 3606)

- Epoxies:
  - Low Viscosity: V-Wrap 770
  - Putty: V-Wrap PF
- Carbon Fabric
  - High Strength: V-Wrap C100 / C200H / C400H
  - High Modulus: V-Wrap C200HM / C400HM
- Glass Fabric:
  - V-Wrap EG50 / EG50B
- Bi-directional:
  - Carbon: V-Wrap C220B
  - Glass: EG50B

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FRP Certification

- Building Officials (ICC-ES) Approved
- NSF Approved (potable water safe)
- UL Approved (fire rated protection)

➢ Manufacturing Facilities Audits
➢ Periodic Testing

ICC EVALUATION SERVICE

NSF APPROVED

UL LISTED

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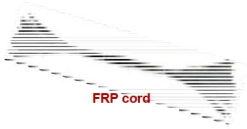
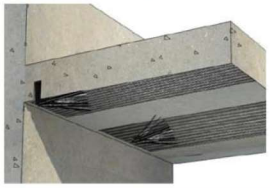
FRP Anchors





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V-WRAP FPS Fire Protection System

- Single-component spray applied material
- Cementitious-based, non-combustible, and non-flammable
- Code Council approved (ESR-3606)

- **Advantages:**
  - UL listed product
  - Up to 4-hour rating
  - Very high bond strength
  - Fast and efficient application
  - Surface Flame Spread: 0
  - Smoke Developed: 0

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V-WRAP FPS TYPICAL APPLICATIONS

UL LISTED

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FRP Design Principles & Engineering Considerations

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FRP Design Guidelines

American Concrete Institute

ACI 440.2R-17

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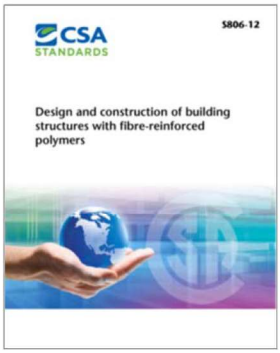
FRP Design Guidelines

Canadian Standards Association

CSA S806-12



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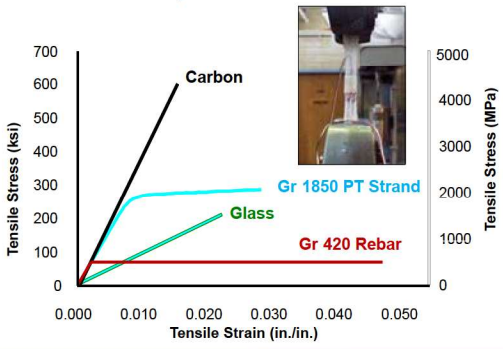
Mechanical Properties of FRP



structural TECHNOLOGIES

FRP Test Methods

Properties	Test Method	Number of Specimens
Tensile Strength	ASTM D3039	20
Elongation	ASTM D3039	20
Tensile Modulus	ASTM D3039	20
Coefficient of Thermal Expansion (CTE)	ASTM D696 or E1142	5
Creep	ASTM D2990	5
Glass Transition Temperature	ASTM D4065	5

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ACI 440.2R Environmental Reduction Factor

Exposure condition	Fiber and resin type	C_E
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment	Carbon/epoxy	0.85
	Glass/epoxy	0.5
	Aramid/epoxy	0.7

$f_{fu} = C_E f^*_{fu}$ Strength

$\varepsilon_{fu} = C_E \varepsilon^*_{fu}$ Elongation

$E_{fu} = \frac{C_E f^*_{fu}}{C_E \varepsilon^*_{fu}} = E^*_{f}$ Modulus

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CSA S806 Environmental Durability Tests

Test	Specification	Condition	Duration	% Retention	
				1000h	3000h
Water Resistance	ASTM D2247 ASTM E104	100% 38 ± 1 °C	1000, 3000, and 10000	90	85
Saltwater Resistance	ASTM D1141 ASTM C581	Immersion at 23 ± 1 °C	1000, 3000, and 10000	90	85
Alkali Resistance	ASTM C581	Immersion in $CaCo_3$ at pH=9.5 and 23 ± 1 °C	1000 and 3000	90	85
Dry Heat Resistance	ASTM D3045	60 ± 3 °C	1000 and 3000	90	85

structural TECHNOLOGIES

FRP Strengthening Limit

ACI 440.2R:

- Loss of FRP should not result in member failure

$$(\emptyset R_n)_{existing} \geq (1.1S_{DL} + 0.75S_{LL})_{new}$$

"Supplemental Reinforcement"

Existing strength without FRP should be sufficient to support typical service loads

FRP Strengthening Limit

CSA S806:

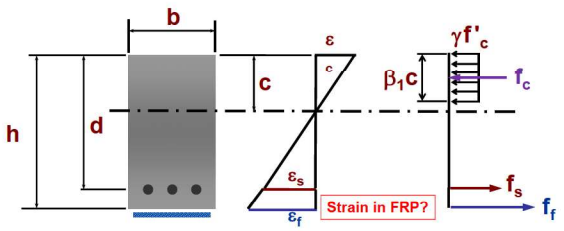
- Loss of FRP should not result in member failure

$$(\emptyset R_n)_{existing} \geq (1.0S_{DL} + 1.0S_{LL})_{new}$$

"Supplemental Reinforcement"

Existing strength without FRP should be sufficient to support service loads

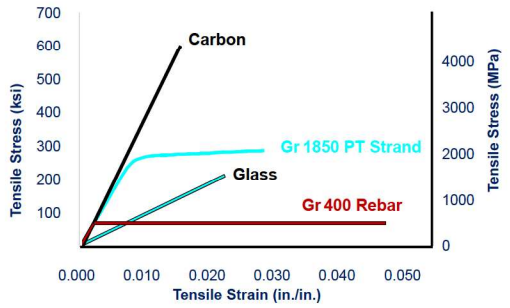
FRP Flexural Design Concepts



$$M_n = A_s f_s \left(d - \frac{\beta_1 c}{2} \right) + \Psi_f A_f f_f \left(h - \frac{\beta_1 c}{2} \right)$$

$= 0.85$

Mechanical Properties of FRP



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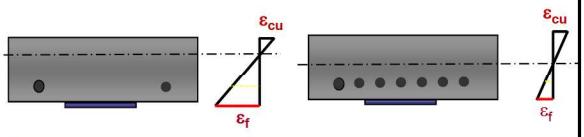
FRP General Design Concepts

Effectiveness of FRP

Strain compatibility design approach



FRP design strength can be 50% of published ultimate strength ($0.5\, f_{fu}$)

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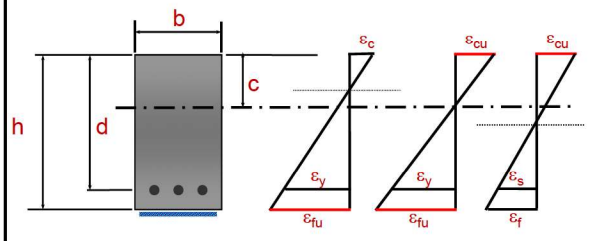
Failure Modes



Failure mode and strain distribution depends on type and amount of FRP reinforcement

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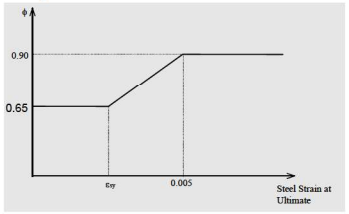
Strength vs. Ductility

ACI 318:
A section with lower ductility should compensate with a higher reserve of strength



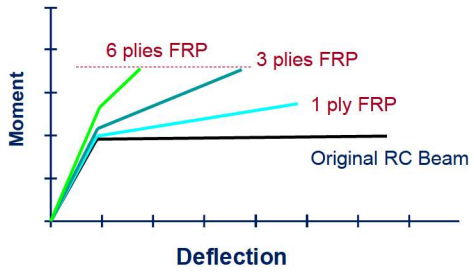
$$\phi = \begin{cases} 0.90 & for \quad \varepsilon_s \geq 0.005 \\ 0.65 + \dfrac{0.20\left(\varepsilon_s - \varepsilon_{sy}\right)}{0.005 - \varepsilon_{sy}} & for \quad \varepsilon_{sy} < \varepsilon_s < 0.005 \\ 0.65 & for \quad \varepsilon_s \leq \varepsilon_{sy} \end{cases}$$

Strength vs. Ductility

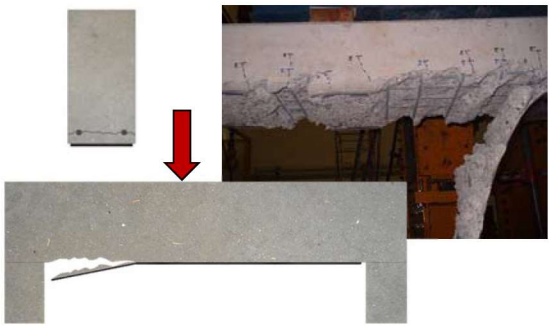
CSA S806-12 Cl. 11.2.1:

Strengthening of a member shall not result in the transformation of a ductile failure mode of the unstrengthened member to a brittle failure mode of the strengthened member

Effect of Adding FRP Plies



Interfacial Shear Failure – Concrete Cover Delamination



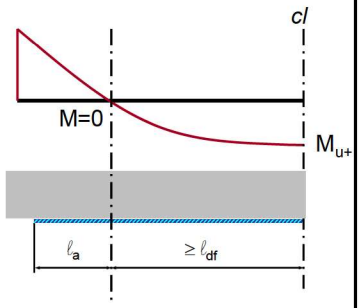
Cut-off Points: Continuous Span

ACI 440.2R

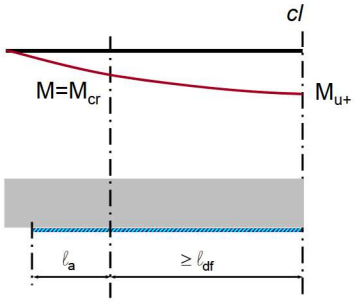
l_a = 150 mm

Cl. 11.3.1.9

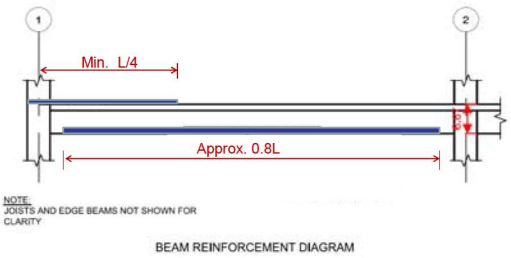
$$1_a = \sqrt{\frac{n_F E_F t_F}{\sqrt{f'_c}}} \geq 300\ mm$$



Cut-off Points: Simple Span



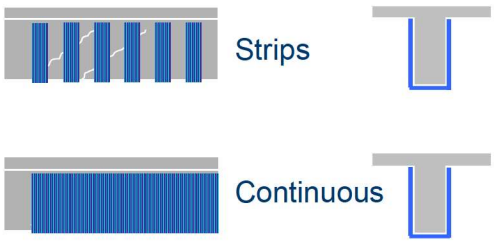
FRP Detailing - Example



BEAM REINFORCEMENT DIAGRAM

SHEAR STRENGTHENING

Various Configurations

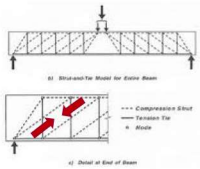


Wrapping Schemes

"U-wrap" "L-wrap" Two sides

Shear Strength

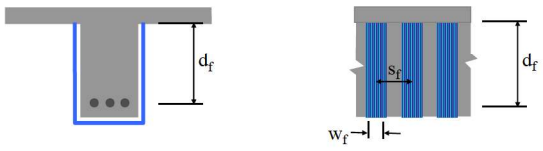
$$V_n = V_c + V_s + \psi_f V_f$$



$$V_s + V_f \le 0.66\sqrt{f'_c}\, b_w d$$

$\psi_f = 0.95$	Completely wrapped members
$\psi_f = 0.85$	Three-sided U-wraps or bonded face plies

FRP Contribution



$$V_f = \frac{A_{fv} f_{fe} d_f}{s_f}$$

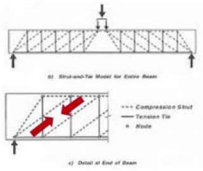
$$f_{fe} = \kappa_v f_{fu} \le 0.004 E_f$$

Shear Strength

CSA S806-12 Cl. 11.3.2.5

- The factored shear resistance (V_r) of the retrofitted beam

$$V_r = V_c + V_s + V_F$$



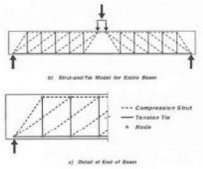
d_v: Effective shear depth for internal steel equal to 0.9d or 0.72h, whichever is greater

Shear Strength

CSA A23.3-19

$$V_s = \frac{\varphi_s A_v f_y d_v}{s}$$

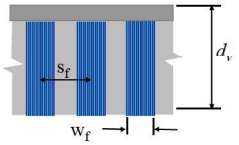
$$V_c = \varphi_c \lambda \beta \sqrt{f'_c}\, b_w d_v$$



d_v: Effective shear depth for internal steel equal to 0.9d or 0.72h, whichever is greater

Shear Strength

$\varphi_c = 0.65$
$\varphi_s = 0.85$
$\varphi_F = 0.65$



CSA S806-12 Cl. 11.3.2.6

$$V_F = \frac{\varphi_F A_F E_F \varepsilon_F d_v}{s_F}$$

$$f_F = E_F \varepsilon_F$$

d_v: Effective shear depth for internal steel equal to 0.9d or 0.72h, whichever is greater

α_F: The orientation angle of the fibers with respect to the longitudinal axis of the member

θ: Acute angle of fiber direction to member axis

Effective FRP strain

$$\varepsilon_F = 0.006 \le 0.75\varepsilon_{Fu}$$ Fully-wrapped

$$\varepsilon_F = 0.005 \le 0.75\varepsilon_{Fu}$$ U-wrapped with proven anchorage system

$$\varepsilon_F = \underbrace{\kappa_v \varepsilon_{Fu}}_{\text{Limit for debonding failure mode}} \le \underbrace{0.004}_{\text{Limit for loss of aggregate interlock}}$$ U-wrapped without anchoring or side bonded

$$\kappa_v = \frac{k_1 k_2 L_e}{11{,}900\,\varepsilon_{fu}} \le 0.75$$

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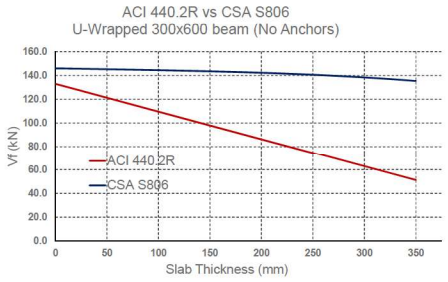
CSA S806-12 vs. ACI 440.2R-17

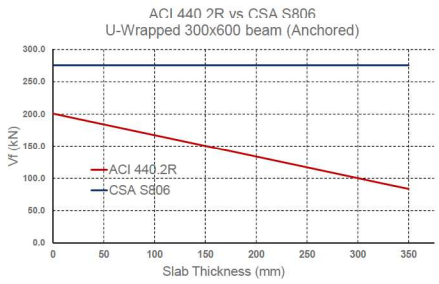
- Shear strengthening of beams (no FRP anchors)



structural TECHNOLOGIES

CSA S806-12 vs. ACI 440.2R-17

- Shear strengthening design of beams (with FRP anchors)



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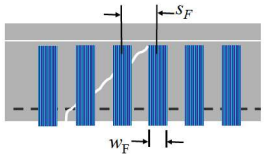
Shear strengthening limitations

CSA S806-12 Cl. 11.3.2.3, 11.3.2.4:

Beams with total depth less than 300 mm shall not be strengthened for shear unless fully wrapped on all four faces or a proven anchorage system is used to develop the design strength of the FRP

Shear Strengthening - Detailing

Spacing Requirements

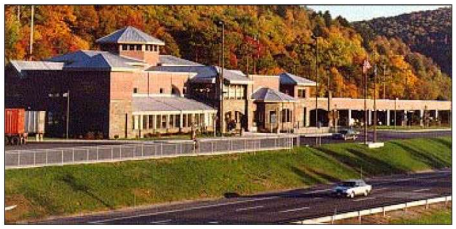


$$s_F \le \begin{matrix} w_F + 0.25 d_v \\ w_F + 300mm \end{matrix}$$

FRP strips shall be placed between steel stirrups rather than over the steel stirrups

Shear Strengthening - Detailing

- Minimum corner radius for shear strengthening is not defined for beams
- Minimum corner radius is 12 mm (ACI 440.2R)
- Minimum corner radius for columns is 20 mm (Cl. 11.4.2.2)



PARKING GARAGE

PRECAST DOUBLE TEE AND CORBEL STRENGTHENING

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Existing Conditions

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Precast Tee FRP Strengthening

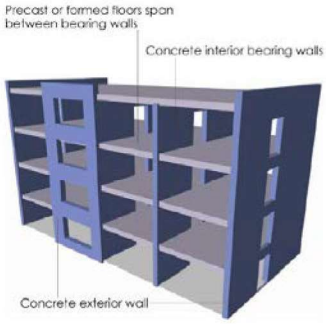
structural TECHNOLOGIES

Precast Tee FRP Strengthening


Corbel FRP Strengthening


Corbel FRP Strengthening


Shear Walls



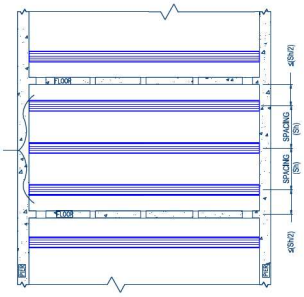
Shear Walls

Diagonal Shear Failure

Shear Walls Shear Strengthening

$$V_n = V_c + V_s + \psi_f V_f$$

$$V_f = m\, n_f t_f f_f D$$



m = 0.75 for walls strengthened on one face
m = 2 for walls strengthened on both faces
D' = Wall length

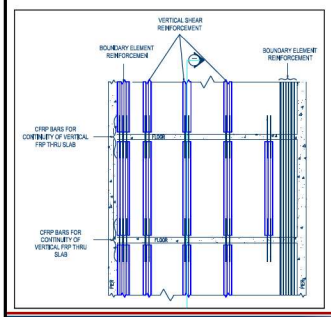
Shear Walls Strengthening

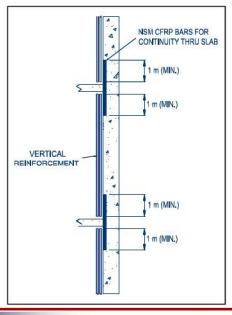
FRP solution

structural TECHNOLOGIES

Shear Walls Strengthening

FRP solution





structural TECHNOLOGIES

Shear Walls Strengthening

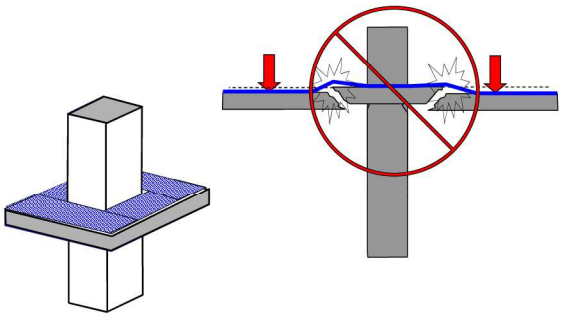
FRP solution

structural TECHNOLOGIES

Shear Walls Strengthening

Surface Embedded FRP Bars

FRP Applications - Punching Shear?



Confinement

Column Hinge Failure

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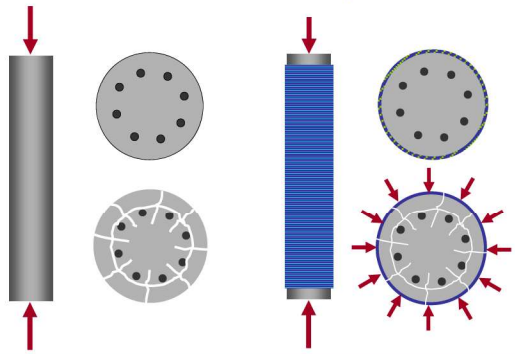
General Concept



structural TECHNOLOGIES

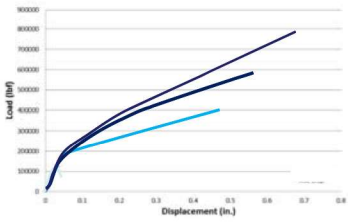
FRP Confined Column

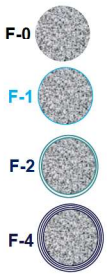
F-0 F-1 F-2 F-4

Cylinder ID	V-Wrap C200H
F-0	--
F-1	1 layer
F-2	2 layers
F-4	4 layers

structural TECHNOLOGIES

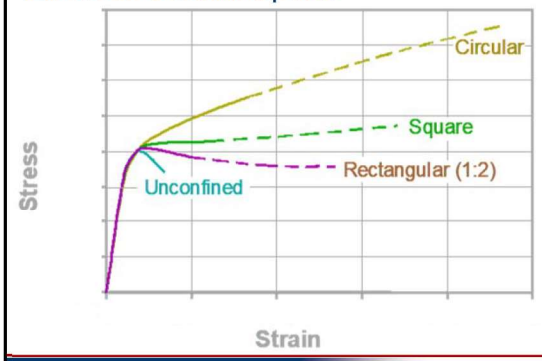
FRP Confined Column





structural TECHNOLOGIES

Effect of Column Space



structural TECHNOLOGIES

Axial Strength

- ACI 318

$$\varphi P_n = 0.85\varphi\left[0.85 f'_{cc}\left(A_g - A_{st}\right) + f_y A_{st}\right]$$

$$\varphi P_n = 0.80\varphi\left[0.85 f'_{cc}\left(A_g - A_{st}\right) + f_y A_{st}\right]$$

structural TECHNOLOGIES

Axial Strength

- CSA A23.3

Spirally reinforced columns

$$P_{r,\max} = 0.90 P_{ro}$$

Tied columns

$$P_{r,\max} = (0.2 + 0.002h) P_{ro} \le 0.80 P_{ro}$$

$$P_{ro} = \alpha_1 \, \varphi_c \, f'_{cc} (A_g - A_{st}) + \varphi_s \, f_y \, A_{st}$$

Column Confinement

$$f_{cc}^{'} = f_c^{'} + 3.3 \psi_f \kappa_a f_l$$

$$f_l = \frac{2 E_f n t_f \varepsilon_{fe}}{D}$$

$\psi_f = 0.95$

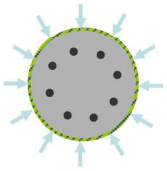
$\varepsilon_{fe} - \kappa_\varepsilon \varepsilon_{fu}$ $\quad \kappa_\varepsilon = 0.55$

$\kappa_a = 1$

$\kappa_b = 1$

$$\varepsilon_{ccu} = \varepsilon_c' \left(1.5 + 12 \kappa_b \frac{f_l}{f_c'} \left(\frac{\varepsilon_{fe}}{\varepsilon_c'} \right)^{0.45} \right) \le 0.01$$

Strain limit to prevent excessive cracking and loss of concrete integrity



Column Confinement

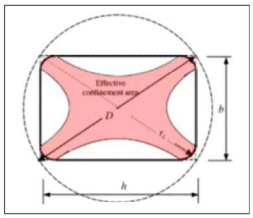
$$f_{cc}^{'} = f_c^{'} + 3.3 \psi_f \kappa_a f_l$$

$$\varepsilon_{ccu} = \varepsilon_c' \left(1.5 + 12 \kappa_b \frac{f_l}{f_c'} \left(\frac{\varepsilon_{fe}}{\varepsilon_c'} \right)^{0.45} \right) \le 0.01$$

$$\kappa_a = \frac{A_e}{A_c} \left(\frac{b}{h} \right)^2$$

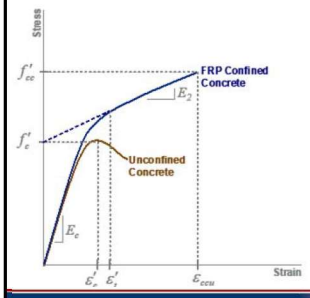
$$\kappa_b = \frac{A_e}{A_c} \left(\frac{h}{b} \right)^{0.5}$$

$$\frac{A_e}{A_c} = \frac{1 - \dfrac{\left[\left(\frac{b}{h} \right) (h - 2r_c)^2 + \left(\frac{h}{b} \right) (b - 2r_c)^2 \right]}{3bh} - \rho_g}{1 - \rho_g}$$



Column Confinement (CSA S806)

Confined Compressive Strength of Concrete (f'_{cc})



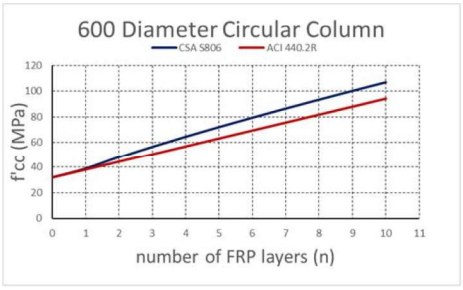
$$f'_{cc} = 0.85 f'_c + k_1 k_c f_1$$

$$k_1 = 6.7(k_c f_1)^{-0.17}$$

$$k_c = \begin{cases} 1 & \text{Circular} \\ 0.4 & \text{Rectangular} \end{cases}$$

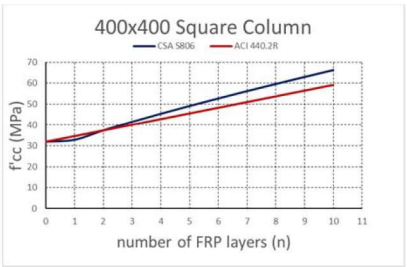
CSA S806-12 vs. ACI 440.2R-17

- Confinement of a **circular column** using FRP under **pure axial load**



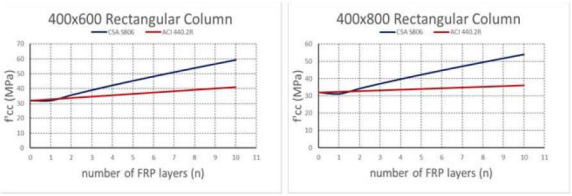
CSA S806-12 vs ACI440.2R-17

- Confinement of a **square column** using FRP under **pure axial load**



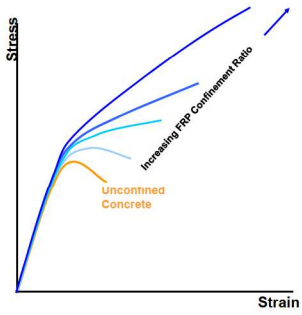
CSA S806-12 vs. ACI 440.2R-17

- Confinement of a **rectangular column** using FRP under **pure axial load**



structural TECHNOLOGIES

Column Confinement

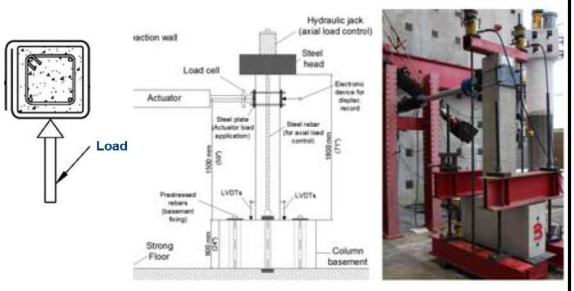


Light FRP confinement will exhibit "descending branch" and should be avoided.

$$\frac{f_l}{f_c'} > 0.08$$

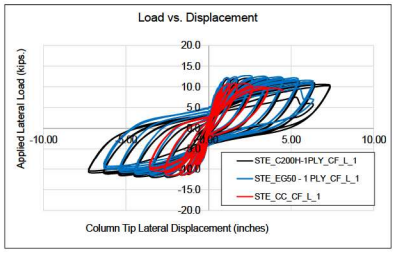
structural TECHNOLOGIES

Column Plastic Hinge Confinement



structural TECHNOLOGIES

Column Plastic Hinge Confinement



No FRP

1 ply C200H carbon

Column FRP Shear Strengthening

Seismic Tests of RC Columns (ST – 2017)

Seismic Design of Reinforced Concrete (J. Moehle – 2015)

ACI 440.2R Shear Design Method

$$V_n = V_c + V_s + V_f$$

$A_f = 2n_f t_f w_f$

FRP design strain: $\varepsilon_{fe} = \boxed{0.004} \leq 0.75\varepsilon_{fu}$

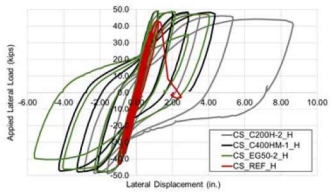
FRP effective stress: $f_{fe} = E_f \varepsilon_{fe}$

FRP nominal Shear Strength: $V_f = \frac{A_f}{s_f} f_{fe} d_f$

$$V_n \leq \left(V_c + 8\sqrt{f_c'} b_w d\right) \approx 10\sqrt{f_c'} b_w d$$

Column FRP Shear Tests

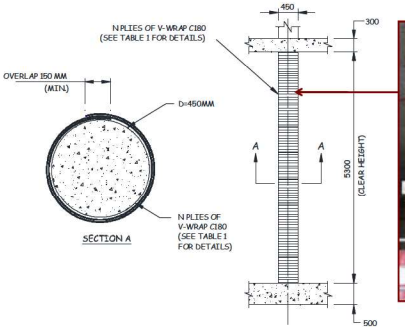
- Full Scale Tests



structural TECHNOLOGIES

Landmark Plaza Rehabilitation

Repair Details – Column FRP



structural TECHNOLOGIES

FRP Quality Control

structural TECHNOLOGIES

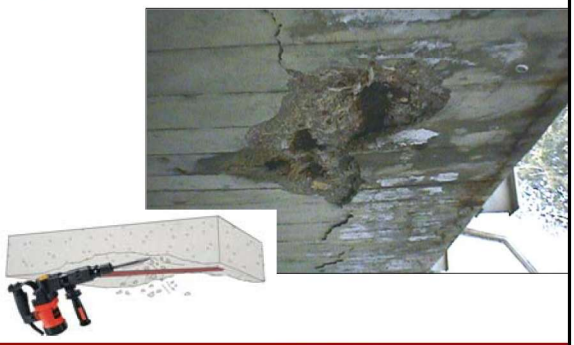
FRP Quality Control

- Precautions before installation
- Surface preparation
- Detailing
- Proper saturation of FRP sheet
- Quality assurance testing for
  - Intimate contact/bond
  - Bond strength
  - FRP tensile properties

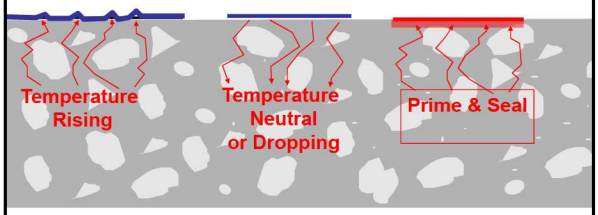
Installation Precautions…

TEMPERATURE BELOW 40°F | WET SURFACE | GASSING FROM TEMPERATURE RISE | REBAR CORROSION

Repair Substrate!



Gassing - Prevention and Precaution



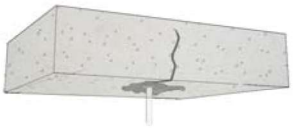
Surface Prep - Methods and desired surface

- Abrasive Blast
- Dustless Grinding & Vacuum
- Water Blast & Dry

CSP 3

Inject Cracks

- Crack Repair – Epoxy inject cracks larger than 0.25 mm

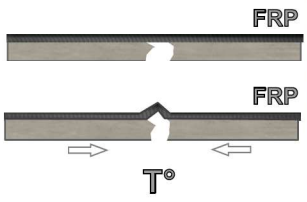


Abrasive Blast Makes Cracks Visible!

structural TECHNOLOGIES

FRP Failure Due to Improper Crack Repair

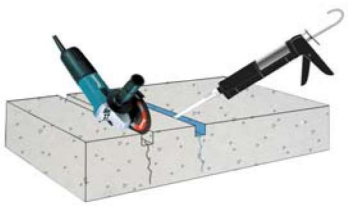
- FRP failure due to improper crack repair



structural TECHNOLOGIES

Slab Crack Repair – Grout Crack & Gravity Feed

- Rout and seal cracks larger than 0.25 mm



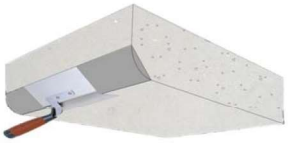
structural TECHNOLOGIES

If Fiber Direction Is Perpendicular to Corner

Column corners

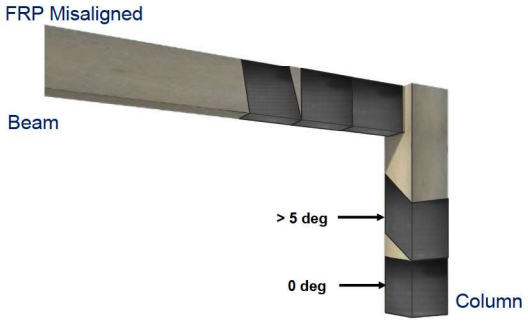
Beam corners

Rounding of Corners



FRP Over Rounded Corner on Column

If Corner Is Not Evenly Rounded…



Quality Control – Saturation Process

FRP Sheet Installation

Sounding Bond Tests

Quality Control - Delamination Test

Small Delamination Repair Procedure

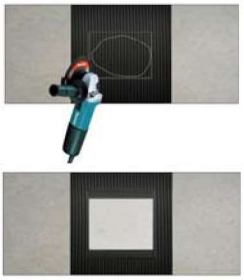
Insert resin into delamination

- Less than 13 cm² or 5% Total Area Max
  - OK. No repair required
- If 13 to 30 cm²
  - Inject with low pressure

Large Delamination Repair Procedure

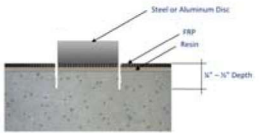
Remove/Replace FRP:

- If greater than 30cm^2 grind or sawcut area
- Replace w/equivalent sheets
- Minimum repair lap = 150mm



FRP Pull-off Test

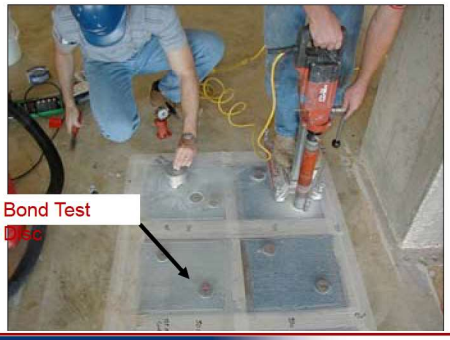
Acceptance Criteria - Minimum bond = 1.4 MPa (200 psi)



Bond Test Location and Frequency

1 PULL PER INSTALLATION DAY MINIMUM OR PER ENGINEER'S SPEC (per m^2 installed)

Pre-Installation Pilot Bond Pull-off Testing?



QA Procedures for FRP Properties

Material Properties

- Witness panels to evaluate strength, strain, & modulus
- Test panels from field materials
- ASTM D3039 test method

FRP QA/QC

Witness Panel Test

Tensile Test – ASTM D3039

1.2. TEST RESULTS

Table 1.2 - Tensile Test Results for C40GHM fabric with V-Wrap 770 resin, per ASTM D3039

Specimen ID	Average width, w		Area, A		Peak load, P^{max}		Load/unit width, P^{max}/w		Strength, F^{u}		Modulus, E^{u}
	mm	in.	mm²	in²	kN	lbs	kN/mm	lbs/in.	MPa	ksi	GPa
C40GHM_TNS1_01	22.58	0.889	45.86	0.071	71.23	16006	3.15	18004	1551.7	225.1	119.4
C40GHM_TNS1_02	21.26	0.837	43.20	0.067	71.39	16042	3.36	19166	1651.8	239.6	117.5
C40GHM_TNS1_03	22.68	0.893	46.09	0.071	72.73	16343	3.21	18301	1577.3	228.8	122.5
C40GHM_TNS1_04	22.68	0.893	46.09	0.071	75.65	17001	3.34	19038	1640.8	238.0	116.7
C40GHM_TNS1_05	22.73	0.895	46.19	0.072	76.41	17171	3.36	19185	1653.5	239.8	117.9
Average	**22.39**	**0.881**	**45.49**	**0.071**	**73.48**	**16513**	**3.28**	**18729**	**1615.0**	**234.2**	**118.8**
S_{n-1}	0.63	0.025	1.29	0.002	2.42	543	0.10	548	47.3	6.9	2.3
CV(%)	2.8	2.8	2.8	2.8	3.3	3.3	2.9	2.9	2.9	2.9	1.9
C40GHM_TNS2_01	22.61	0.890	45.94	0.071	77.45	17405	3.43	19556	1685.4	244.5	128.4
C40GHM_TNS2_02	22.63	0.891	45.99	0.071	69.10	15527	3.05	17426	1501.9	217.8	127.4
C40GHM_TNS2_03	22.53	0.887	45.78	0.071	76.54	17199	3.40	19390	1671.1	242.4	121.4
C40GHM_TNS2_04	22.73	0.895	46.19	0.072	76.61	17215	3.37	19235	1657.7	240.4	113.8
C40GHM_TNS2_05	24.10	0.949	48.96	0.076	78.97	17745	3.28	18699	1611.5	233.7	122.6
Average	**22.82**	**0.902**	**46.58**	**0.072**	**75.73**	**17018**	**3.30**	**18961**	**1625.5**	**235.8**	**122.7**
S_{n-1}	0.67	0.026	1.35	0.002	3.84	862	0.15	864	74.5	10.8	5.8
CV(%)	2.9	2.9	2.9	2.9	5.1	5.1	4.6	4.6	4.6	4.6	4.7
C40GHM_TNS3_01	22.61	0.890	45.94	0.071	78.52	17646	3.47	19827	1708.8	247.8	112.8
C40GHM_TNS3_02	21.82	0.859	44.34	0.069	64.36	14462	2.95	16836	1451.0	210.4	112.8
C40GHM_TNS3_03	22.99	0.905	46.71	0.072	73.97	16623	3.22	18368	1583.0	229.6	121.0
C40GHM_TNS3_04	21.87	0.861	44.44	0.069	71.48	16063	3.27	18656	1607.9	233.2	118.5
C40GHM_TNS3_05	22.20	0.874	45.11	0.070	71.40	16045	3.22	18358	1582.2	229.5	114.4
Average	**22.30**	**0.878**	**45.31**	**0.070**	**71.95**	**16168**	**3.23**	**18409**	**1586.6**	**230.1**	**115.9**
S_{n-1}	0.50	0.020	1.01	0.002	5.14	1154	0.19	1067	91.9	13.3	3.7
CV(%)	2.2	2.2	2.2	2.2	7.1	7.1	5.8	5.8	5.8	5.8	3.2

*Failure mode based on ASTM D3039, refer to Figure 1.1

structural TECHNOLOGIES

Thank You

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structural TECHNOLOGIES

Workshop:

STRUCTURAL STRENGTHENING

Feb. 21, 2020

Matt Hickey, P.Eng.
Division Manager (Ontario)

Jay Thomas
VP of Strengthening Division

Tarek Alkhrdaji, PhD, P.E.
VP of Engineering

structural TECHNOLOGIES PULLMAN

Agenda

- **Introduction & Housekeeping**
- **Differences New Construction vs Strengthening**
- **FRP**
  - Most commonly used FRP applications
  - Installation techniques
  - Design strategy (ACI 440 & CSA S806)
  - FRP limitations & fire protection
  - QC
- **Conventional Techniques**
- **Case Studies**
  - Flexure, Shear, Confinement
- **PT Repairs**
- **ACI 562**
- **Questions….**

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PULLMAN Specialty Contracting Services

- Strengthening of Existing Structures
- Post Tensioning Reinforcement Systems & Repairs

structural TECHNOLOGIES

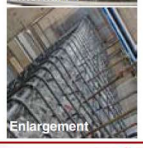
Strengthening Solutions

Applications

- Adaptive reuse
- New penetrations
- Adding new loads

- Construction defects
- Honeycomb and void repairs
- Damage and overloading

- Blast upgrades



structural TECHNOLOGIES

NEW CONSTRUCTION
VS.
STRENGTHENING

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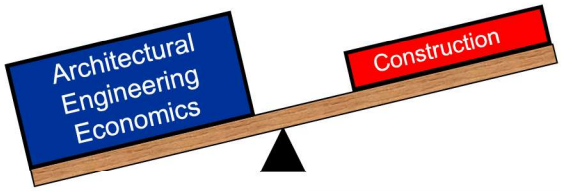
The New Construction Process

Function and Structural Demand



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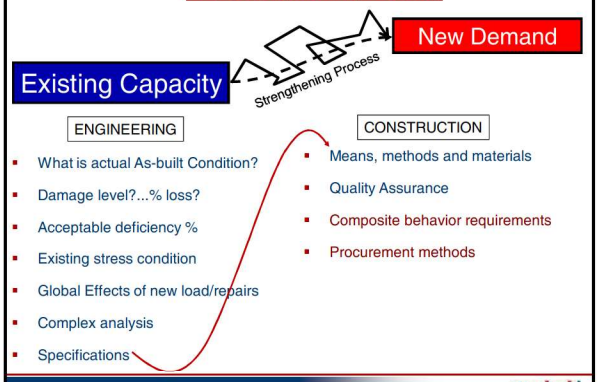
The Strengthening Process



ENGINEERING

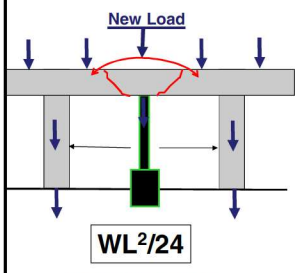
- What is actual As-built Condition?
- Damage level?...% loss?
- Acceptable deficiency %
- Existing stress condition
- Global Effects of new load/repairs
- Complex analysis
- Specifications

CONSTRUCTION

- Means, methods and materials
- Quality Assurance
- Composite behavior requirements
- Procurement methods

structural TECHNOLOGIES

Strengthening Limitations- Global effects of repairs



$WL^2/24$

Span shortening

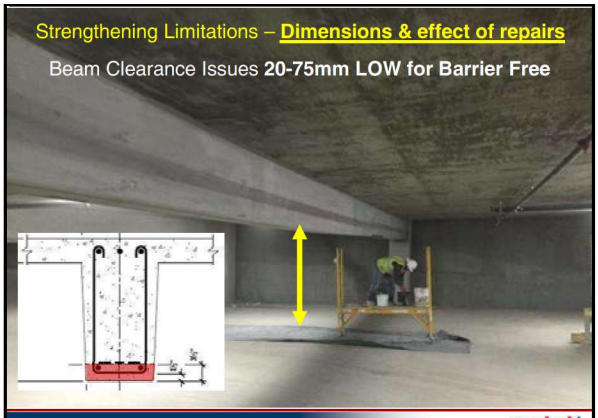
Global Effects of Repairs- Dimensional Limits

structural TECHNOLOGIES

Global Effects of Repairs- **Dimensional Limits**

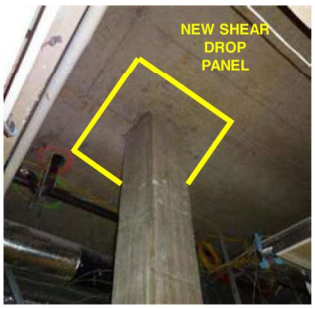
Strengthening Limitations – **Dimensions & effect of repairs**

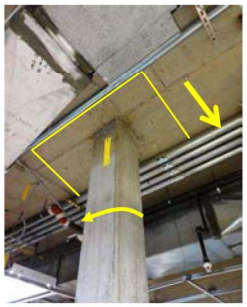
Beam Clearance Issues **20-75mm LOW for Barrier Free**



Global Effects of Repairs- **Dimensional Limits- Egress**

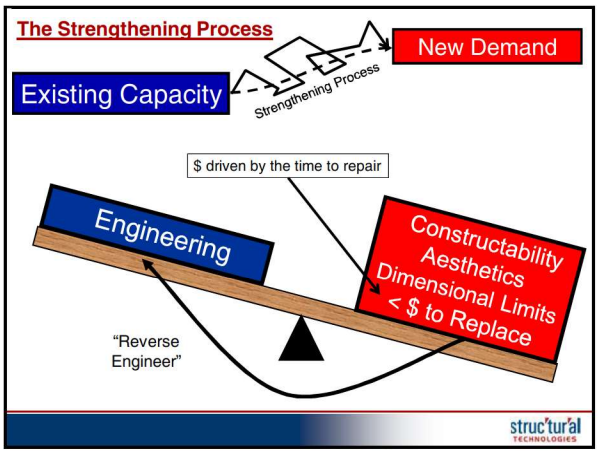
Strengthening Limitations - Access to Structure

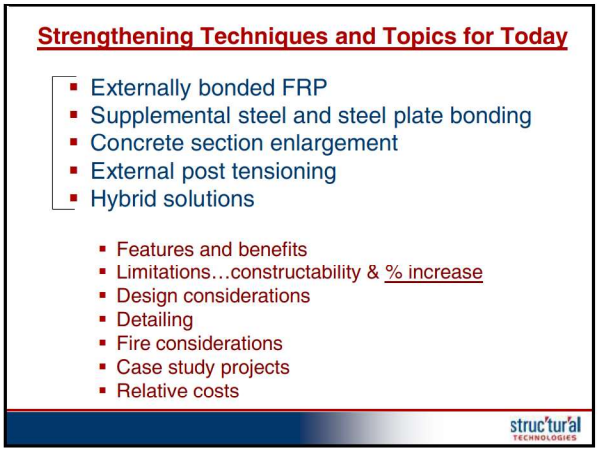


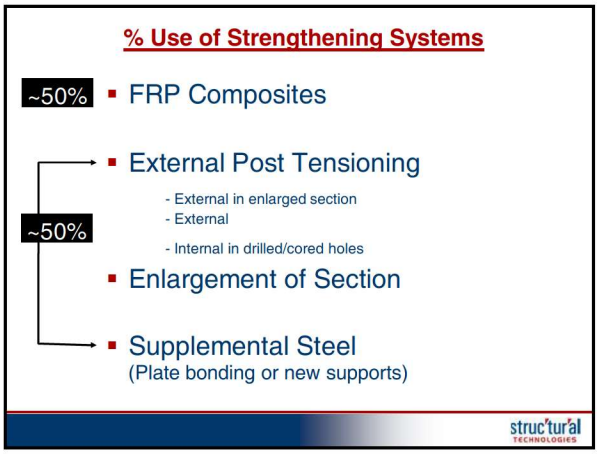


Strengthening Limitations – Accesd to Work Building Operations During Repair

Strengthening Limitations - Access During Repair


The Strengthening Process
New Demand
Existing Capacity
Strengthening Process
$ driven by the time to repair
Engineering
Constructability
Aesthetics
Dimensional Limits
< $ to Replace
"Reverse Engineer"
structural TECHNOLOGIES


Strengthening Techniques and Topics for Today
Externally bonded FRP
Supplemental steel and steel plate bonding
Concrete section enlargement
External post tensioning
Hybrid solutions
Features and benefits
Limitations…constructability & % increase
Design considerations
Detailing
Fire considerations
Case study projects
Relative costs
structural TECHNOLOGIES


% Use of Strengthening Systems
~50%
FRP Composites
~50%
External Post Tensioning
- External in enlarged section
- External
- Internal in drilled/cored holes
Enlargement of Section
Supplemental Steel
(Plate bonding or new supports)
structural TECHNOLOGIES

EXTERNALLY BONDED FRP

PART 1

CONVENTIONAL STRENGTHENING

PART 2

Supplemental steel supports and plate bonding

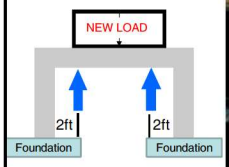
Supplemental Supports with Steel Beam

Headroom restrictions?...Composite with RC beam?

Span shortening with steel beams

Span shortened only 600mm at each end to use existing foundation

$WL^2/24$

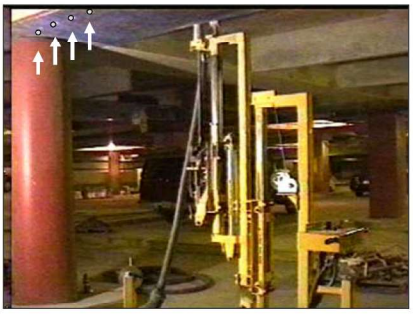


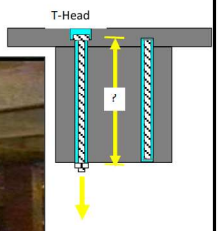
Supplemental Steel for Shear Upgrade

External high strength bars or through bolted plates

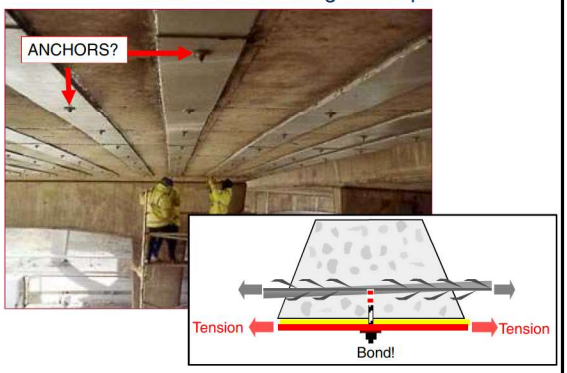
Supplemental Steel for Shear Upgrade

Internal high strength bars or rebar

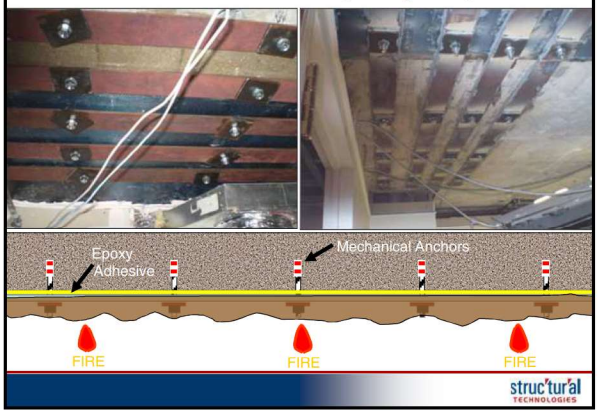




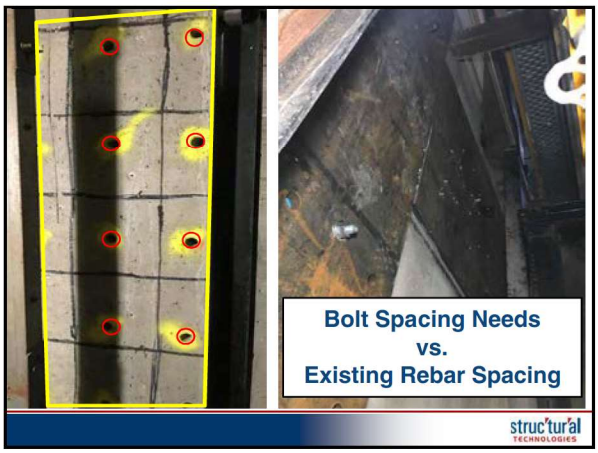
Steel Plate Bonding Concept



Steel Plate Installation "Dry-Fitting" Components



Steel Plate Installation



CONVENTIONAL STRENGTHENING

Part 3

Section Enlargement with Concrete

Concrete Enlargements - **Advantages** and **Considerations**

- **Advantages:**
  - Known and commonly used materials & design
  - Fire rating is easily defined and calculated
  - Offers **considerable increase** in capacity
  - Additional stiffness
- **Considerations:**
  - Additional dead load
  - Added section depth may offset additional dead load
  - Loss of headroom or other dimensional issues?
  - Requires very flowable materials
  - Potential damage to existing steel by drilling dowels
  - ***MUST*** *create* ***"Composite Behavior"*** *between new and old concrete*

Enlargement- Specifying & Measuring Surface Preparation

- Concrete to Concrete BOND created by:

1. Horizontal shear transfer
   a. Through installation of steel dowels
   b. Profiling of concrete surface (CSP-6)
2. Surface prep that profiles & opens the concrete pores
3. A placement techniques to force intimate contact between exiting and new concrete

1. Locate Steel, Drill and Clean holes for dowels

- Type of Drill?
- Hole Cleaning?
- Wire Brush
- HALF Pullout Strength results based on drill type and cleaning!

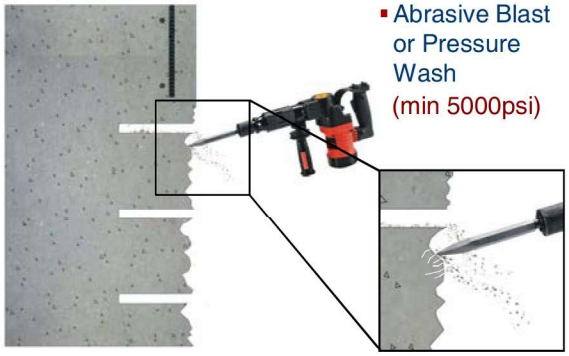
2. Roughen Surface to min 3/16" Profile

- Chip
- Hydro-Blast (20k psi)
- Spongeblast

2. Roughen surface to min CSP-6 profile

3. After Chipping Open Pores of the Concrete

- Abrasive Blast or Pressure Wash (min 5000psi)

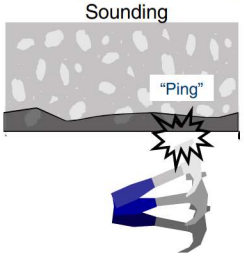


Roughen Surface to CSP-6 Profile w/15 lb. Max Chipping Gun

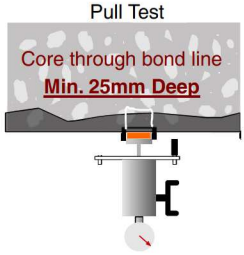
WHY 15# MAX.?

Quality Control to Confirm Bond

Sounding

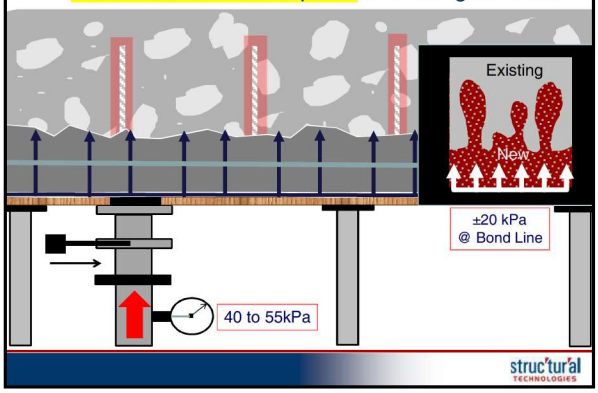


Pull Test



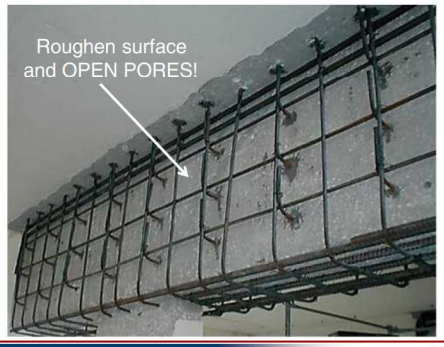
> 1.5 MPa = **Excellent Bond**
1.0 to 1.5 MPa = Good Bond
0.75 to 1.0 MPa = Average Bond
< 0.75 MPa = **Poor Bond**

4. Install rebar and formwork, place new material AND force material into the pores of existing concrete



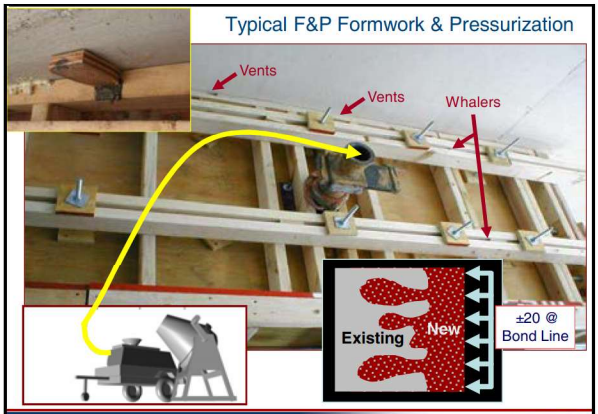
Strengthening solutions Enlargement with Form and Pump pressurized placement

Strengthening solutions Enlargement with Form and Pump pressurized placement for BOND



structural TECHNOLOGIES

Typical F&P Formwork & Pressurization

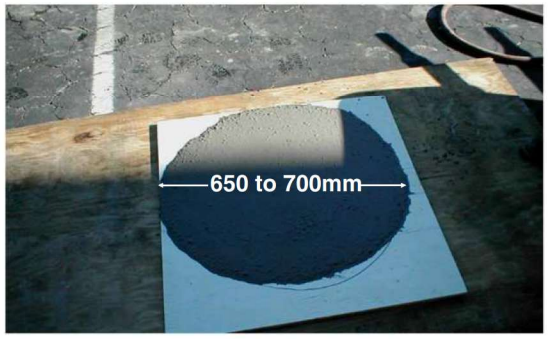


structural TECHNOLOGIES

Strengthening solutions Enlargement with Form and Pump pressurized placement for BOND

structural TECHNOLOGIES

Enlargement- SCC

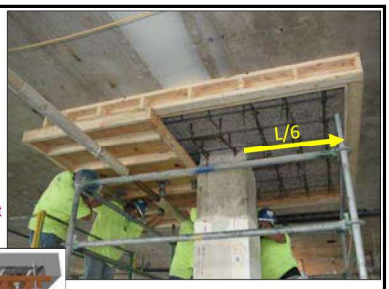


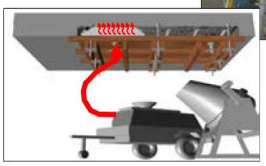
SCC Concrete Placement

Office Building Renovation with the Addition of "Green Roof"

Slab deficient in:
+M, -M & punching shear

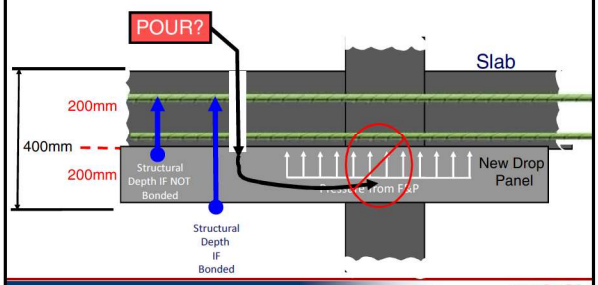
Strategies:
1. FRP top and bottom
   & small PS drop panel
2. Drop capital span/6
   for PS, -M and possibly
   +M?
3. Form & Pump placement





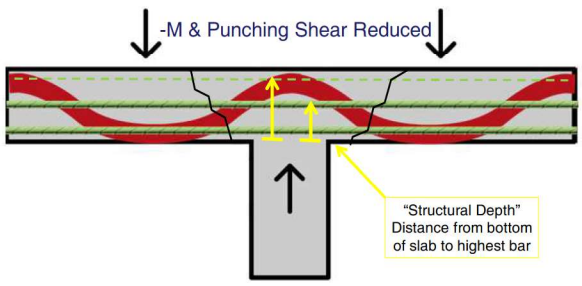
structural TECHNOLOGIES

Strengthening Solutions
Structural effect adding drop panels and the importance of bond



structural TECHNOLOGIES

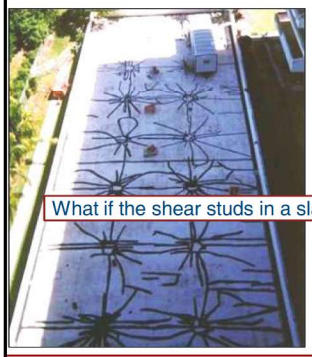
TYPICAL APPLICATIONS FOR DROP PANELS

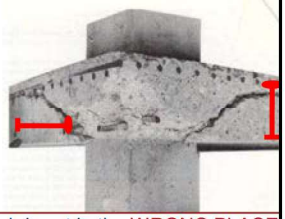


What if the top steel in a slab is set in the TOO DEEP?

structural TECHNOLOGIES

APPLICATIONS FOR SECTION ENLARGEMENT





What if the shear studs in a slab is set in the WRONG PLACE

structural TECHNOLOGIES

Punching Shear Failure- Corrosion of LOW top bars

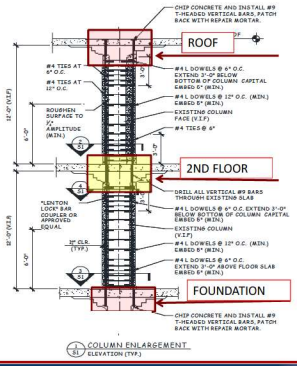
structural TECHNOLOGIES

Strengthening solutions Enlargement with Form and Pump pressurized placement for BOND

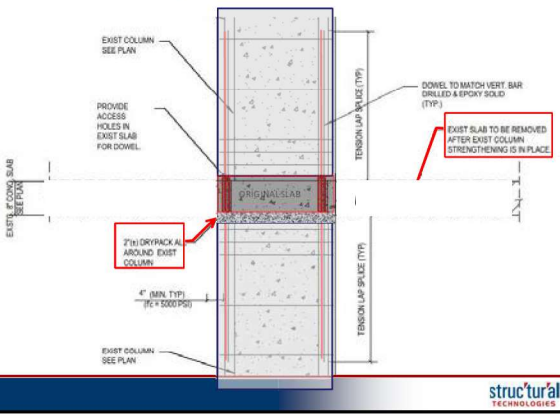
structural TECHNOLOGIES

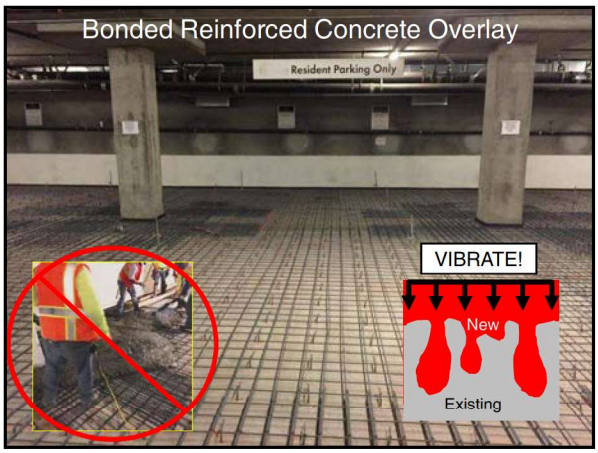
Strengthening solutions Column Enlargement with Form and Pump

Strengthening solutions Column Enlargement w/Continuous Vertical Bar

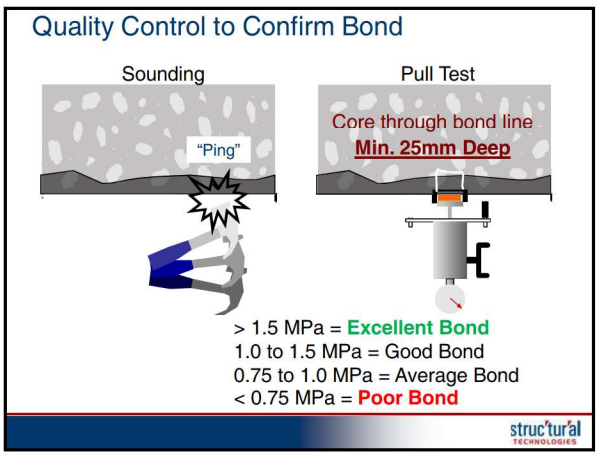


Column Enlargement for Slab Removal- New Atrium



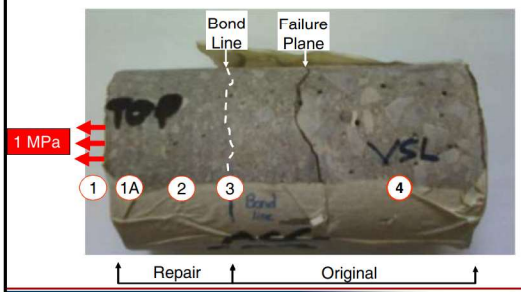

Bonded Reinforced Concrete Overlay
Resident Parking Only
VIBRATE!
New
Existing


Strengthening solutions Bonding reinforced concrete overlay
Using a Vibrator to Consolidate Traditional Concrete
structural
TECHNOLOGIES


Quality Control to Confirm Bond
Sounding
Pull Test
"Ping"
Core through bond line
Min. 25mm Deep
> 1.5 MPa = Excellent Bond
1.0 to 1.5 MPa = Good Bond
0.75 to 1.0 MPa = Average Bond
< 0.75 MPa = Poor Bond
structural
TECHNOLOGIES

Quality Control for Bond

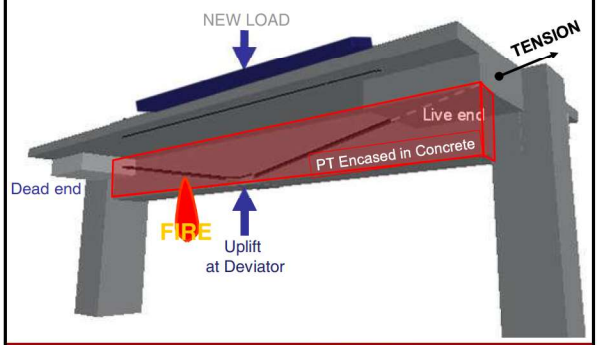
WHERE IS BEST LOCATION TO FAIL? WHY?



CONVENTIONAL STRENGTHENING
Part 4

External Post Tensioning

Strengthening solutions External Post Tensioning



Ext Post Tensioning Design and Detail Considerations

- External PT or cast into concrete enlargement? (fire or aesthetics)
- Sizable increase in capacity
- Tendon draped or deviated at 1 or 2 points?
- Anchorage detailing critical
- Excessive uplift forces (reverse)
- Sequential loading/stressing

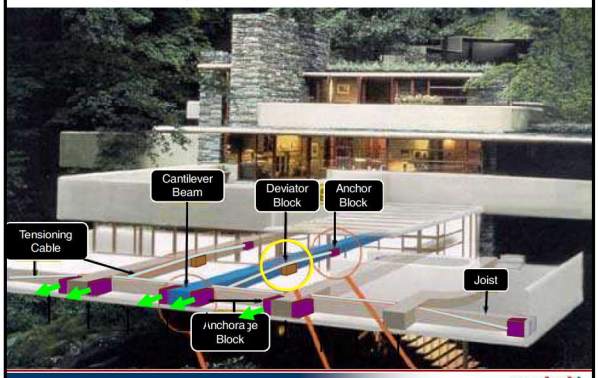
Strengthening Solutions Slab External Post Tensioning

Fire & Maintenance Considerations

Strengthening Solutions External Post Tensioning

Fallingwater

Strengthening Solutions External Post Tensioning



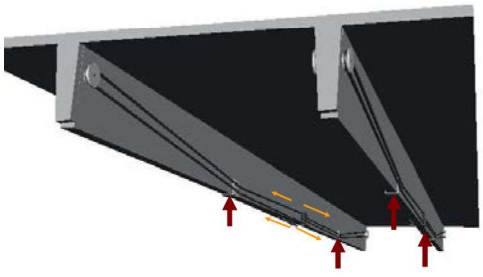
structural TECHNOLOGIES

Strengthening Solutions External Post Tensioning

Home Depot garage upgrade for higher truck loads

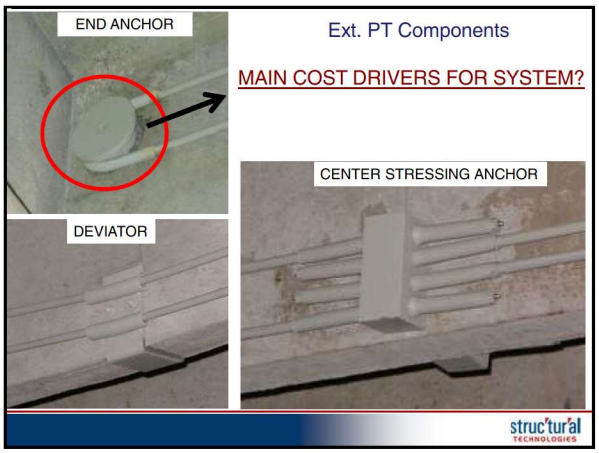
structural TECHNOLOGIES

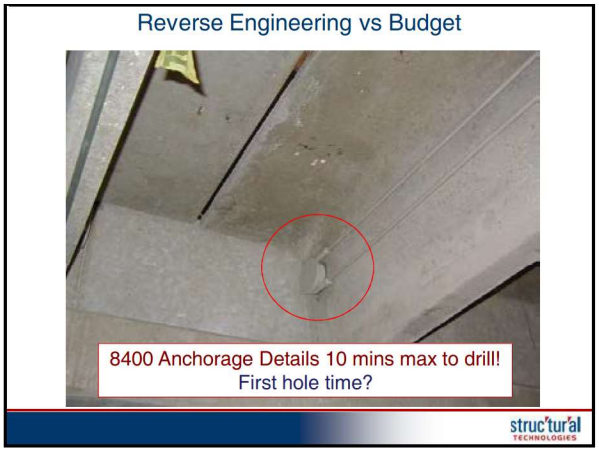
Strengthening Solutions External Post Tensioning of 2T

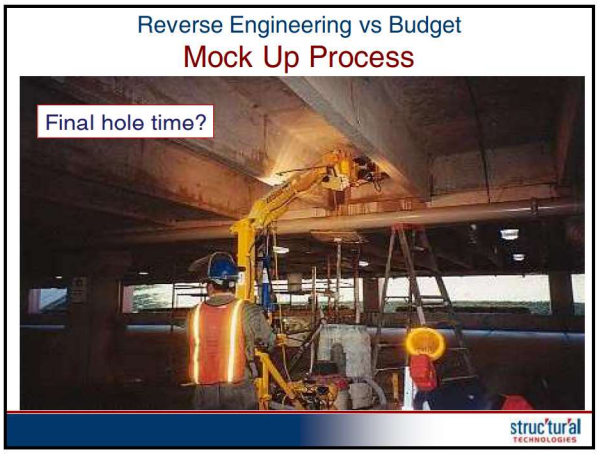


EXAMPLE OF ECONOMIC BASED REVERSE ENGINEERING

structural TECHNOLOGIES

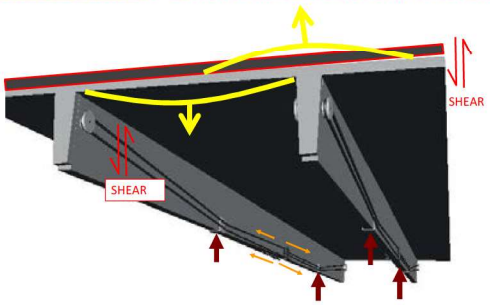

END ANCHOR
Ext. PT Components
MAIN COST DRIVERS FOR SYSTEM?
CENTER STRESSING ANCHOR
DEVIATOR
structural
TECHNOLOGIES


Reverse Engineering vs Budget
8400 Anchorage Details 10 mins max to drill!
First hole time?
structural
TECHNOLOGIES

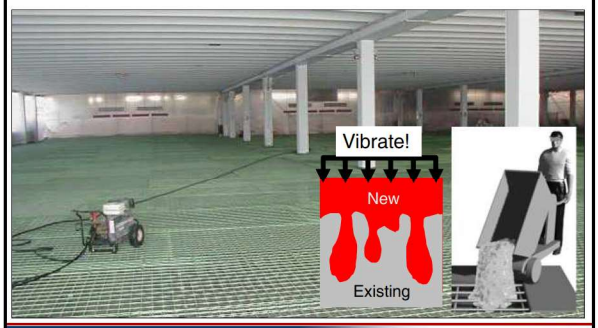

Reverse Engineering vs Budget
Mock Up Process
Final hole time?
structural
TECHNOLOGIES

Strengthening Solutions Strengthening of 2T

GLOBAL EFFECTS **OF LOAD INCREASE AND STRENGTHENING?**



Strengthening Solutions Enlargement with Reinforced Concrete Overlay



FRP Strengthening
T stem shear & inverted T for bending

Strengthening of Beam/Column Connections

Supplemental steel

Failed from Overloading

- What is the Existing Capacity?
- Shoring during repairs?
- $ to Remove vs. replace?

Garage Beam Failed from Overloading

REMOVE OR REPLACE?

Strengthening solutions- External PT and enlargement

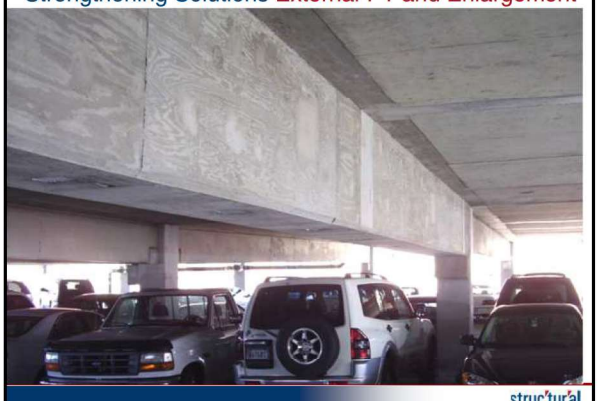
Crack and concrete repairs

structural TECHNOLOGIES

Strengthening solutions EXISTING CAPACITY?

Enlargement designed for 100% of factored loads

Strengthening Solutions External PT and Enlargement

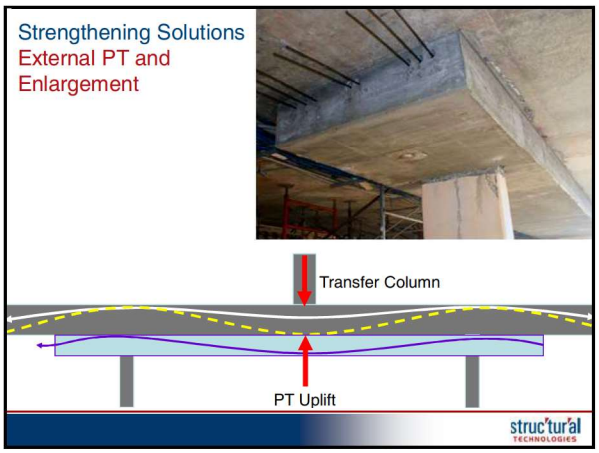


structural TECHNOLOGIES

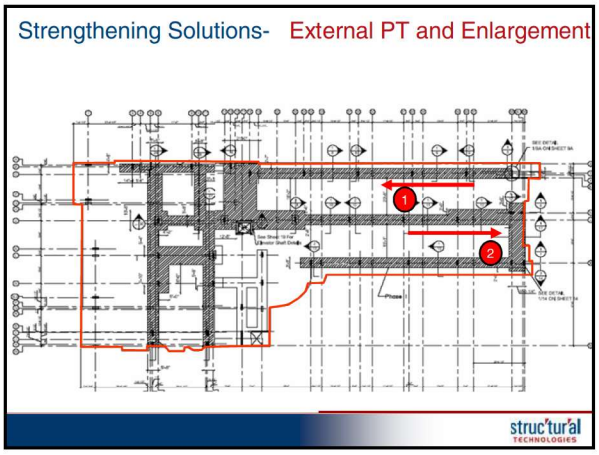

Strengthening Solutions External PT and Enlargement
structural
TECHNOLOGIES


Shoring Needs During Upgrades?
structural
TECHNOLOGIES


Shoring Needs During Upgrades?
structural
TECHNOLOGIES


Strengthening Solutions
External PT and
Enlargement
Transfer Column
PT Uplift
structural
TECHNOLOGIES


Strengthening Solutions
External PT and Enlargement
Transfer Slab Defects
FROM
$424,900
MODEL OPEN
structural
TECHNOLOGIES


Strengthening Solutions- External PT and Enlargement
1
2
structural
TECHNOLOGIES

Strengthening Solutions- External PT and Enlargement

structural TECHNOLOGIES

Strengthening Solutions- External PT and Enlargement

structural TECHNOLOGIES

Strengthening Solutions- External PT and Enlargement

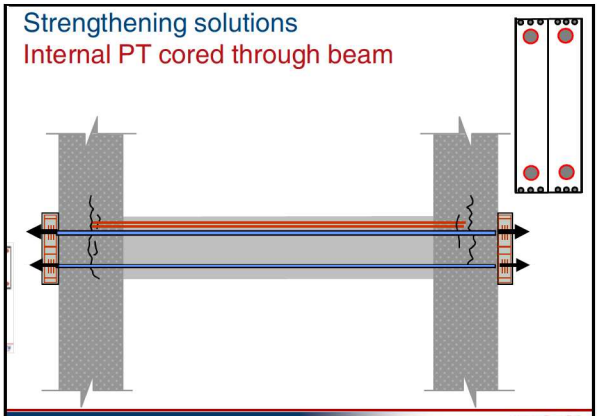
Window in F&P formwork for placement confirmation

structural TECHNOLOGIES

Strengthening Solutions- External PT and Enlargement
Vents in F&P formwork for placement confirmation

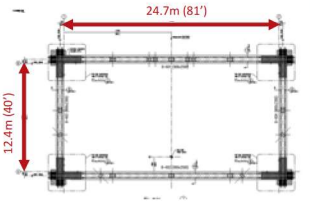
structural TECHNOLOGIES

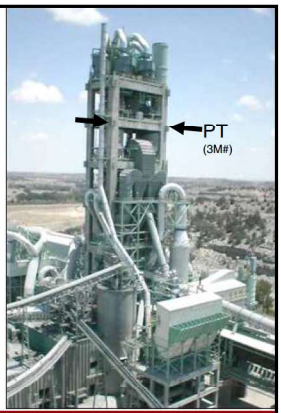
Strengthening solutions
Internal PT cored through beam



structural TECHNOLOGIES

Strengthening solutions internal
PT cored through beam

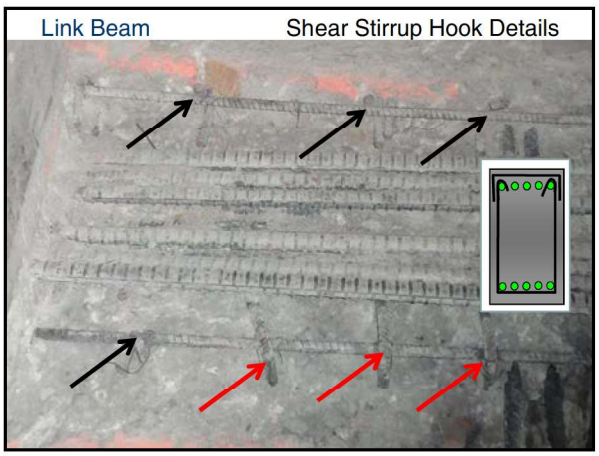


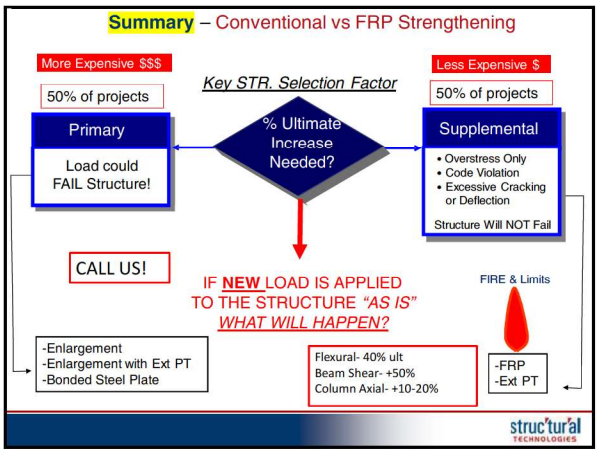


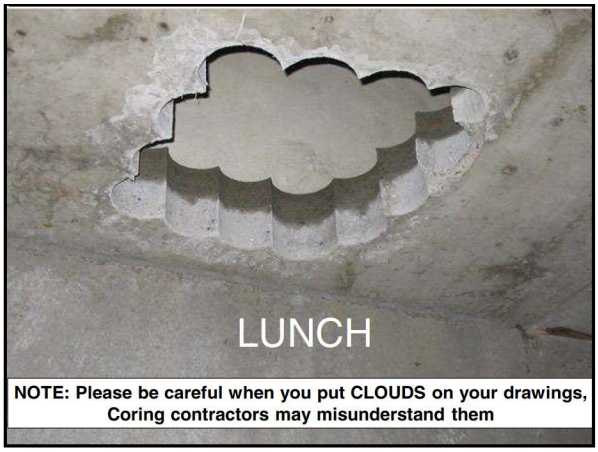
structural TECHNOLOGIES


Demolition Repairs


Link Beam Deficiencies
Aria
Construction Errors
structural
TECHNOLOGIES


Link Beam
Shear Stirrup Hook Details



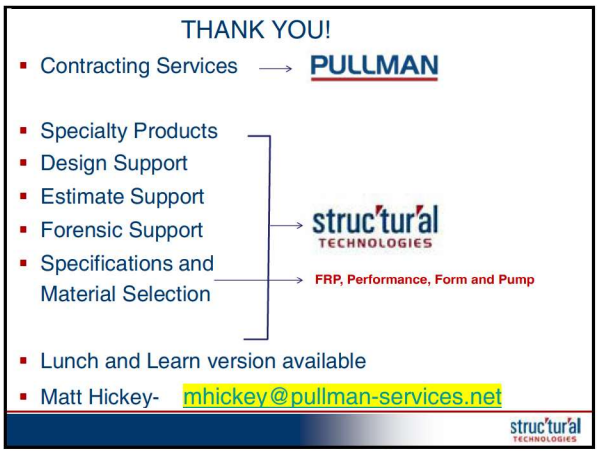


Types of Strengthening Specifications

- Prescriptive...
  Supply step by step procedures, materials and quantities, etc.

- Performance...
  -Supply *Existing Capacity and New Demand.*
  Strengthening design, materials, constructability, etc. are considered to optimize options and costs
  -Attracts experienced, qualified specialty contractors

structural TECHNOLOGIES


THANK YOU!
Contracting Services
PULLMAN
Specialty Products
Design Support
Estimate Support
Forensic Support
Specifications and Material Selection
structural TECHNOLOGIES
FRP, Performance, Form and Pump
Lunch and Learn version available
Matt Hickey- mhickey@pullman-services.net
structural TECHNOLOGIES

Post-Tensioning Concepts, Repairs, Modifications and Evaluation of Existing PT Structures

Jay Thomas
VP Strengthening Division
Structural Technologies

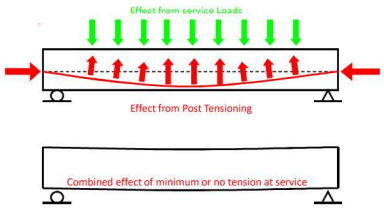
structural TECHNOLOGIES

Basics of Post-Tension

Prestressed Concrete

structural TECHNOLOGIES

Effect of Post Tensioning Combined Effect at Service Loads



"LOAD BALANCING"

◄PREV BASICS NEXT►

structural TECHNOLOGIES

PT BASICS BEAM VIDEO

Post-Tensioned Concrete Ad

Engineering AND Cost Savings

- Design flexibility- LONGER SPANS- LESS COLUMNS
- Structural depth- THINNER, LIGHTER ELEMENTS and STRUCTURE, FOUNDATION LOADS REDUCED
- Controls deflection- SLABS REMAIN UNCRACKED UNDER SERVICE LOADS
- Effective use of high strength concrete
- Height savings- MORE FLOORS/SAME HEIGHT
- Reduces shoring and re-shoring time- AFTER STRESSING, FORMS PULLED

structural TECHNOLOGIES

Typical Prestressing Steel Used for Post Tensioning

Buttonhead Wire

- Ultimate Strength 240ksi
- 0.25" diam

High Strength 7-wire strand

- Ultimate Strength 270 ksi
- Primarily 0.50"- 0.60" diam

Bar Systems

- High Strength
- Threaded

structural TECHNOLOGIES

Evolution of Unbonded PT Systems

1955 Buttonhead wire in paper sheathing

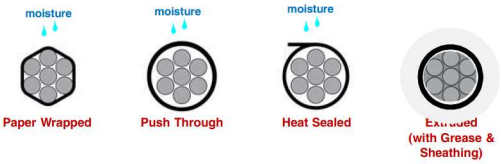
1960 Strand in loose plastic sheathing

1980 Strand in extruded plastic sheathing

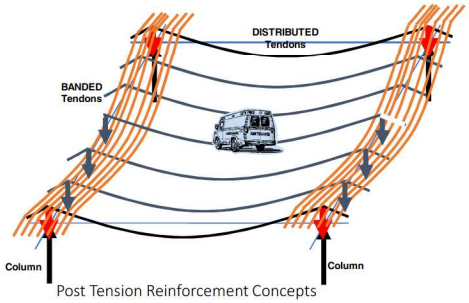
1985-Present Initial encapsulated tendon system

structural TECHNOLOGIES

Evolution of Unbonded PT Sheath Systems



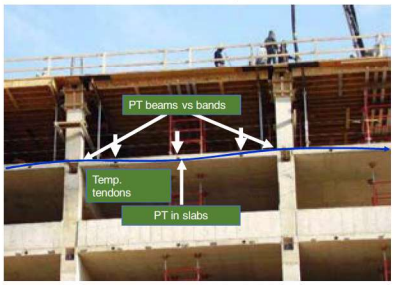
structural TECHNOLOGIES



Post Tension Reinforcement Concepts
2 way slab

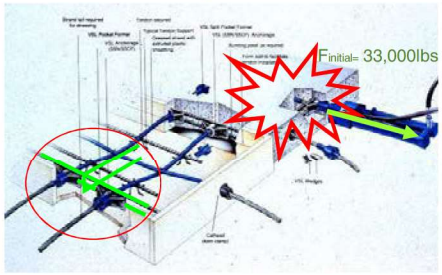
structural TECHNOLOGIES

Post Tensioned Reinforcement Concepts- PT Beams and Slabs



structural TECHNOLOGIES

Post Tension anchorage zone reinforcement details
"Bursting Steel" Slabs



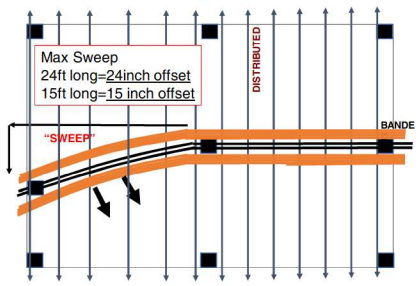
structural TECHNOLOGIES

Post Tension anchorage zone reinforcement details
"Bursting Steel" Beams

structural TECHNOLOGIES

Post Tension anchorage zone reinforcement details

"Sweep Hairpins"



structural TECHNOLOGIES

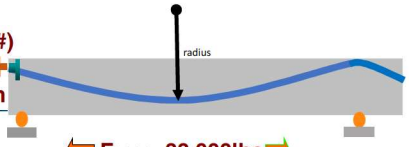
PT Concepts

Hairpins

structural TECHNOLOGIES

Post Tension Concepts Stressing Forces, Losses & Elongation

Force (33k#) vs. Elongation *8in/100ft*



$F_{initial}$= 33,000lbs

F_{final}= 27,000lbs...WHY?

Anchor seating loss + Friction loss from drape, relaxation

structural TECHNOLOGIES

QC Stressing Logs to Confirm Uniform Force in Strands

Confirms proper Elongation vs Force=

8006 HAUTE COURT, SPRINGFIELD, VA 22150
PHONE: 703/451-4300 FAX: 703/451-0862

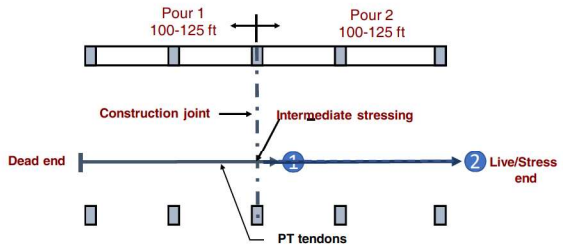
MONOSTRAND STRESSING RECORD

JOB NAME: Wilton House — JOB NO.: 6/22/1905
LOCATION: Arlington VA — DATE: 1/1/2004
FLOOR: 10 POUR: 1 GAUGE NO.: 2/28/1914 RAM NO.: 5173

STRESSED BY				VERIFIED BY			
TENDON NO.	GAUGE PRESSURE JACKING	GAUGE PRESSURE LIFT OFF	CALC ELONG	MEASURED ELONGATION END 1	MEASURED ELONGATION END 2	MEASURED ELONGATION TOTAL	% DEV.
1	7000		7 1/4	7 1/2		7 1/2	3%
2	7000		7 1/4	7 7/8		7 7/8	9%
3	7000		7 1/4	7 1/4		7 1/4	0%

structural TECHNOLOGIES

Post Tension Reinforcement Concepts- Pour Sequence Intermediate Stressing

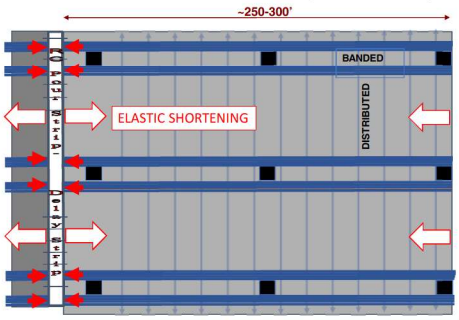


structural TECHNOLOGIES

Post Tension Reinforcement Concepts- Intermediate Stressing

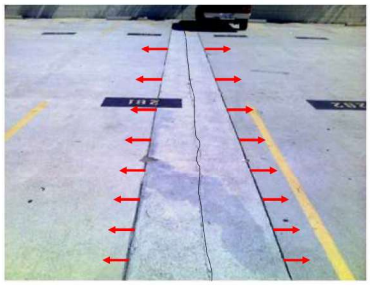
structural TECHNOLOGIES

Post Tension Reinforcement Concepts- Pour Strip



structural TECHNOLOGIES

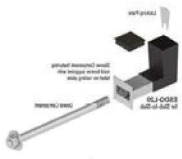
Post Tension Reinforcement Concepts- Pour Strip placed too early!

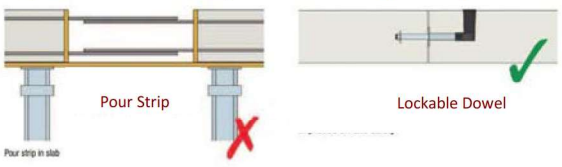


structural TECHNOLOGIES

Post Tension Reinforcement Concepts-

Pour Strip vs. Lockable Dowels to Shorten Sequence

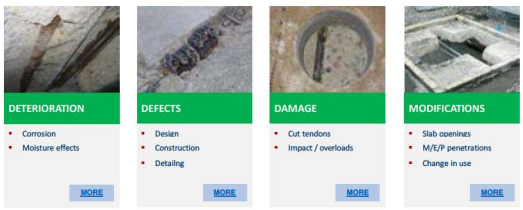




Common Problems with Post-Tensioned Concrete

structural TECHNOLOGIES

Common Problems with Post-Tensioned Concrete



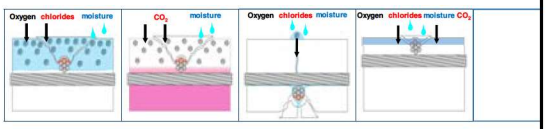
structural TECHNOLOGIES

Common PT Problems: Corrosion of tendons and anchors

◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Common PT Problems: Causes of corrosion on tendons and anchors



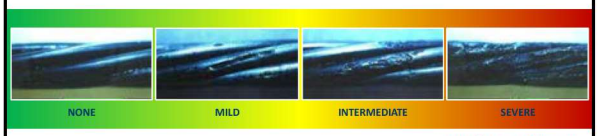
CHLORIDES
Expansion of tendon or anchor, creates spalls & loss of section

CARBONATION
Lowers PH and accelerates corrosion

CRACKS or LOW COVER
Allow corrosion Promoters access to tendon or anchor

structural TECHNOLOGIES

Strand Corrosion / Pitting Classifications

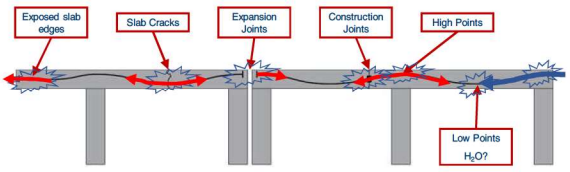


Loss of 3-4 wires under tension... FAILURE!

◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

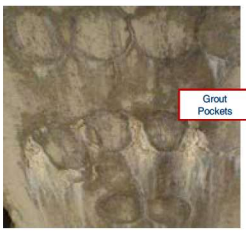
Typical Locations of PT Mild Steel Corrosion

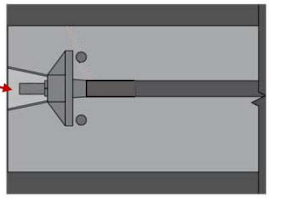


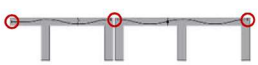
◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Corrosion Locations
Anchorage Zone





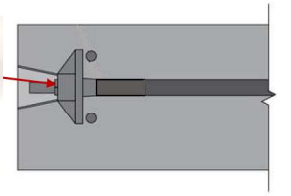


◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Corrosion Locations
Anchorage Zone

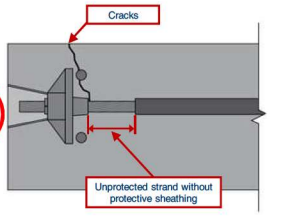
Microscopic View of Anchor Wedges



◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Corrosion Locations
Anchorage Zone



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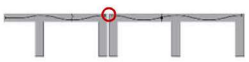
structural TECHNOLOGIES

Corrosion Locations
Expansion Joints

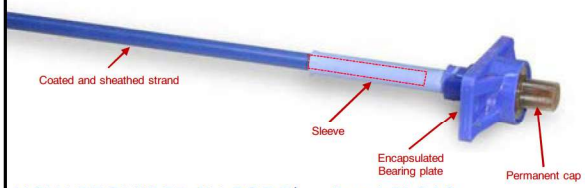


◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Modern Unbonded Monostrand Encapsulated PT Systems

Eliminates water entry into tendon and anchorage



NOW REQUIRED BY CODE! Per ACI 318
(Except slab on grade)

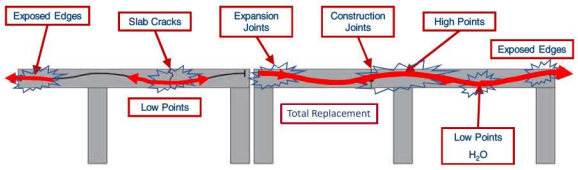
structural TECHNOLOGIES

Repair Strategies for Solving Corrosion or Damage Problems with Post-Tensioned Concrete

structural TECHNOLOGIES

PT Repair Strategies for Corrosion or Damage

Repair options are based on location of distress



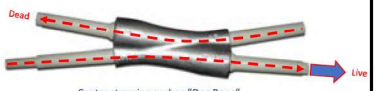
◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Tendon Replacement Splicing and Lock-Off Technologies

Barrel Splice

Temporary Lock Off



Center stressing anchor-"Dog Bone"

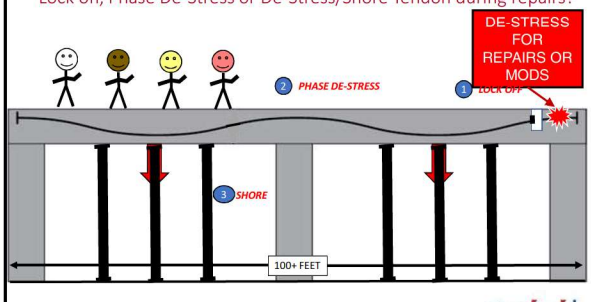
Torque stressing coupler

◄PREV SOLUTIONS NEXT►

structural TECHNOLOGIES

PT Repair Strategies

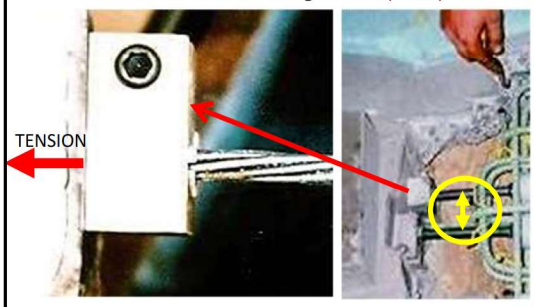
Lock off, Phase De-Stress or De-Stress/Shore Tendon during repairs?



◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Tendon Lock Off Technologies- Temporary Lock Off



structural TECHNOLOGIES

PT Repair Strategy: Anchor Replacement at Slab Edge *with Lock Off*

- De-tension or Lock off?
- Splice on new strand and encapsulated anchor

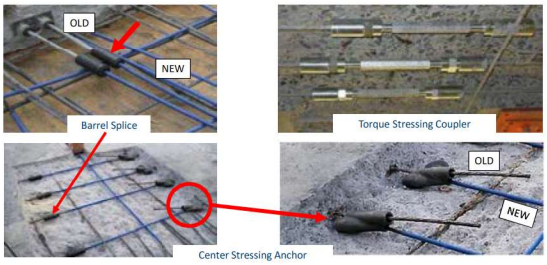
structural TECHNOLOGIES

PT Repair Strategy:

Anchor Replacement at Slab Edge *Shoring and NO Lock Off*

structural TECHNOLOGIES

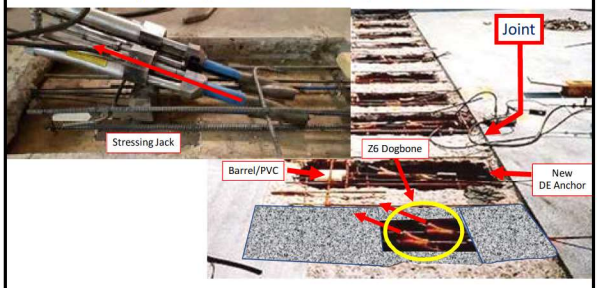
Tendon Replacement Splicing Technologies



◄PREV SOLUTIONS NEXT ►

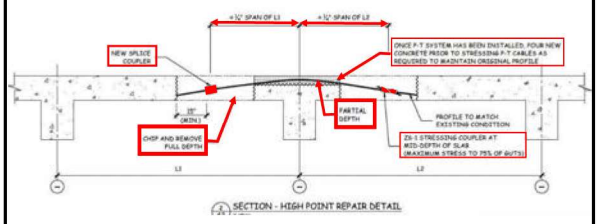
structural TECHNOLOGIES

PT Repair Strategy: At Construction or Expansion Joint Detail



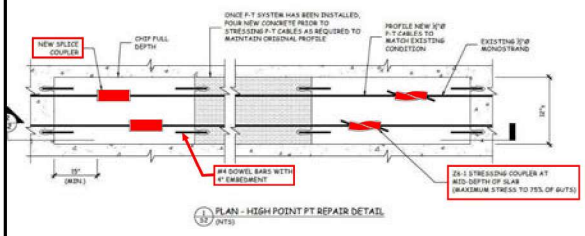
structural TECHNOLOGIES

PT Repair Strategy: High Point Detail

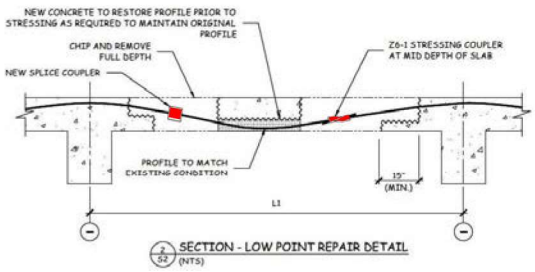


structural TECHNOLOGIES

PT Repair Strategy: High Point Detail

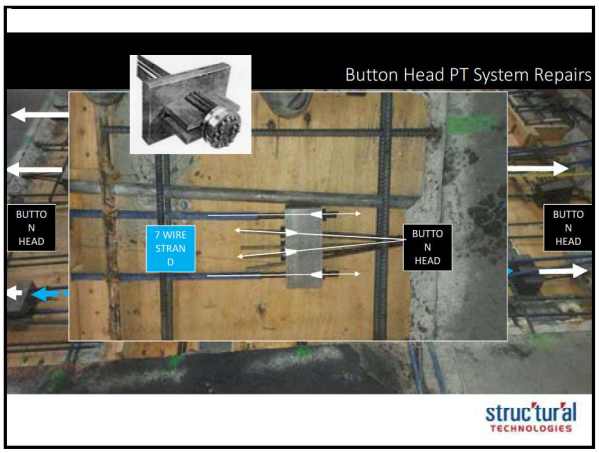


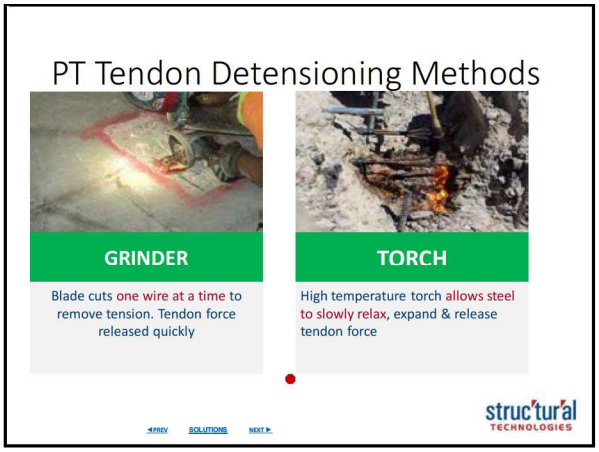
PT Repair Strategy: Low Point Detail

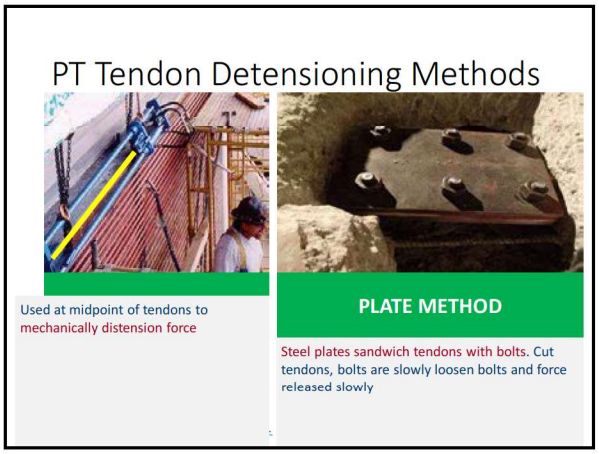


PT Repair Strategy: Full Replacement Tendon- Beam or Slab Detail

OLD TENDON REMOVAL USED TO PULNEW TENDON THROUGH


Button Head PT System Repairs
BUTTO N HEAD
7 WIRE STRAN D
BUTTO N HEAD
BUTTO N HEAD
structural TECHNOLOGIES


PT Tendon Detensioning Methods
GRINDER
Blade cuts one wire at a time to remove tension. Tendon force released quickly
TORCH
High temperature torch allows steel to slowly relax, expand & release tendon force
PREV
SOLUTIONS
NEXT
structural TECHNOLOGIES


PT Tendon Detensioning Methods
Used at midpoint of tendons to mechanically distension force
PLATE METHOD
Steel plates sandwich tendons with bolts. Cut tendons, bolts are slowly loosen bolts and force released slowly

structural TECHNOLOGIES

Common PT Problems: Design and Construction Defects

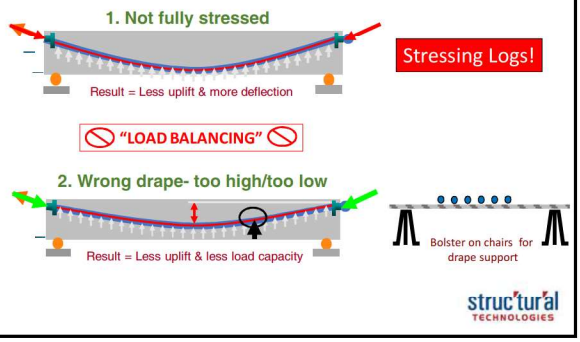
structural TECHNOLOGIES

Common PT Problems: Design and Construction Defects

- Defects in *design, detailing, installation or stressing* may lead to:
  - *Loss* in structural capacity
  - Excess *deflection*
  - *Cracking*
  - Concrete *spalling*
  - Slab edge *splitting*
  - Tendon *bursting* - out of top or bottom of slab
  - Property *damage or injury*

structural TECHNOLOGIES

Common PT Problems: Improper Tendon Stressing or Drape

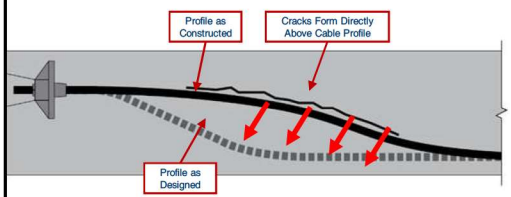


structural TECHNOLOGIES

Misplaced PT Tendons Too Low Chairs/Bolsters not secured

structural TECHNOLOGIES

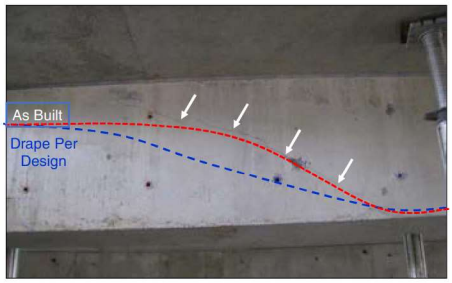
Common PT Problems: Improper Tendon Drape



◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

Common PT Problems: Improper Tendon Drape



structural TECHNOLOGIES

Common PT Problems: Damaged Tendons

CORING/CHIPPING | SAW CUTTING | CONCRETE SCREWS

◄PREV PROBLEMS NEXT►

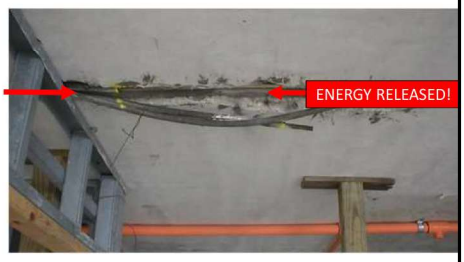
structural TECHNOLOGIES

PT Blowout at High Point From corrosion, damage or anchor slip

◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

PT Blowout at LOW Point From *corrosion**, damage or anchor slip



*Broken corroded tendons do not always exit the concrete- WHY?

◄PREV PROBLEMS NEXT►

structural TECHNOLOGIES

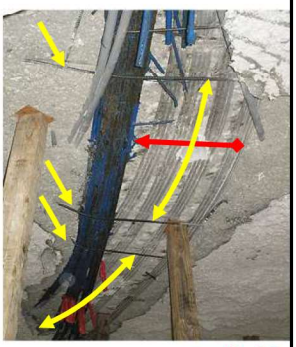
Common PT Problems Cracks from Overload or Loss of PT Force

Higher sense of concern for structural cracking due to PT precompression forces

structural TECHNOLOGIES

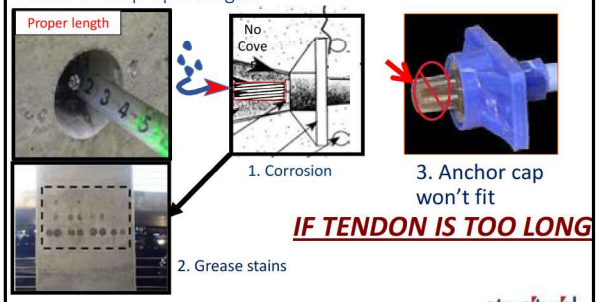
PT Sweep "Blowouts"

- Common Causes:
  - Inadequate "Hairpins" (confinement)
  - Sharp tendon sweeps



structural TECHNOLOGIES

Common PT Problems Cutting Excess Tendon
What is the proper length?



IF TENDON IS TOO LONG

structural TECHNOLOGIES

Cutting Excess Tendon
What is the proper method

Grinder? Torch

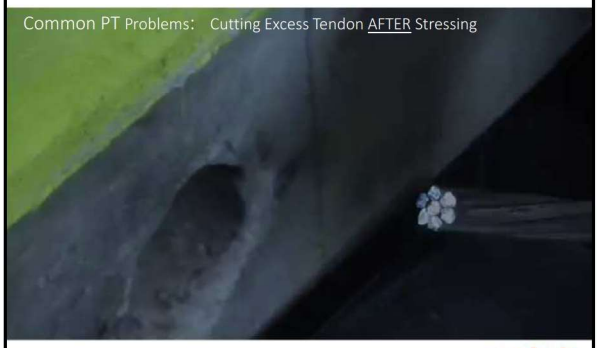
structural TECHNOLOGIES

Common PT Problems: Cutting Excess Tendon AFTER Stressing

PER ACI 318 AFTER CUTTING
-Cap on in 6 hrs
-Grout pocket in 1 day

structural TECHNOLOGIES

Common PT Problems: Cutting Excess Tendon AFTER Stressing



structural TECHNOLOGIES

Common PT Problems: Tendon cut after stressing BUT STILL TOO LONG

structural TECHNOLOGIES

Common PT Modifications: New Openings or Penetrations

structural TECHNOLOGIES

Large and Small New Openings in PT Slabs

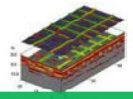


New staircases
Mechanical openings

Elevator shafts/ducts

struc'tur'al TECHNOLOGIES

New PT Slab Opening Procedure (Overview)



1) ANALYSIS / DESIGN

- Analyze structural effect of slab opening
- Load changes in adjacent bays?
- If needed design proper shoring

2) FIELD PREPARATION

- Locate and mark the existing PT tendons

3) FIELD PT WORK

- Remove concrete over tendons at opening perimeter
- Lock off OR detension tendons?
- Demo opening
- Place new anchorages and reinforcement
- Place concrete
- Stress tendons

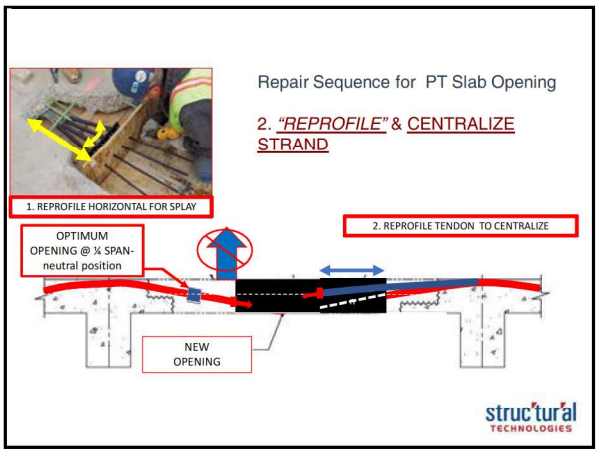
◄PREV PROBLEMS NEXT►

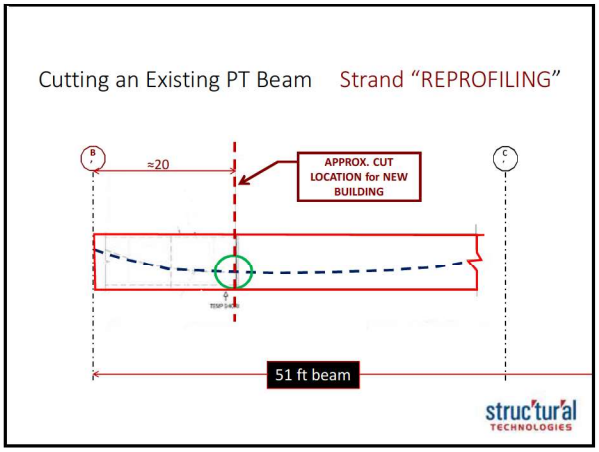
struc'tur'al TECHNOLOGIES

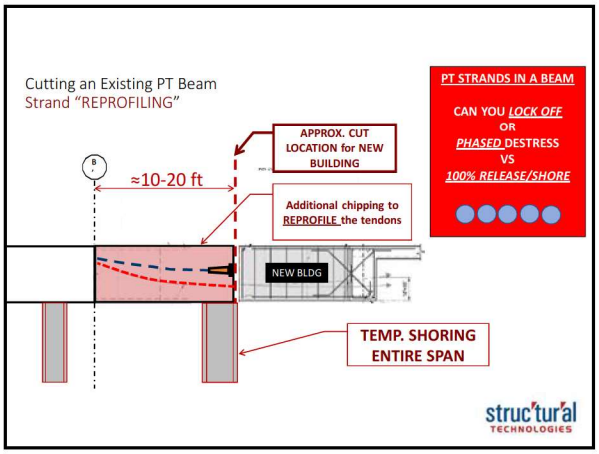
Repair Sequence for PT Slab Opening

1. Create new anchor zone

struc'tur'al TECHNOLOGIES


Repair Sequence for PT Slab Opening
2. "REPROFILE" & CENTRALIZE STRAND
1. REPROFILE HORIZONTAL FOR SPLAY
2. REPROFILE TENDON TO CENTRALIZE
OPTIMUM OPENING @ ¼ SPAN- neutral position
NEW OPENING
structural TECHNOLOGIES


Cutting an Existing PT Beam Strand "REPROFILING"
≈20
APPROX. CUT LOCATION for NEW BUILDING
51 ft beam
structural TECHNOLOGIES


Cutting an Existing PT Beam
Strand "REPROFILING"
PT STRANDS IN A BEAM
CAN YOU LOCK OFF OR PHASED DESTRESS VS 100% RELEASE/SHORE
APPROX. CUT LOCATION for NEW BUILDING
≈10-20 ft
Additional chipping to REPROFILE the tendons
NEW BLDG
TEMP. SHORING ENTIRE SPAN
structural TECHNOLOGIES

Completed Large Slab Openings

New atrium

New stairs

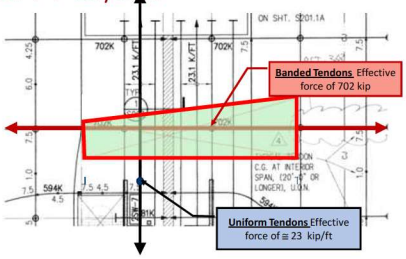
structural TECHNOLOGIES

Case Study – Large Openings in PT Slab using Phased PT Release Approach

Large opening to accommodate new stairs

structural TECHNOLOGIES

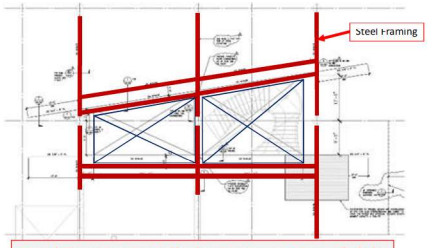
Case Study - Original PT Layout



structural TECHNOLOGIES

Case Study-

New Steel Framing Plan around Opening

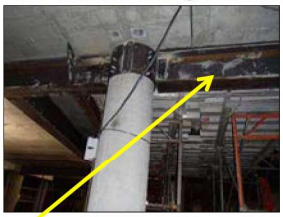


Steel Framing installed prior to cutting of slab

structural TECHNOLOGIES

Case Study-

New Steel Framing Plan around Opening



Steel beams and collars installed at perimeter of new slab opening

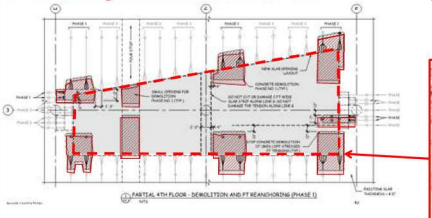
Shoring and decking installed to create work platform for concrete demolition and PT repairs

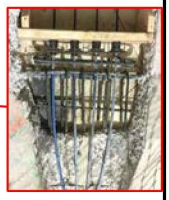
structural TECHNOLOGIES

Case Study-

PT Phasing and Demolition Plan

Phase 1

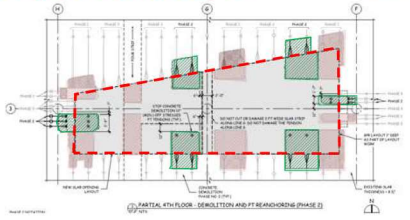




structural TECHNOLOGIES

Case Study-

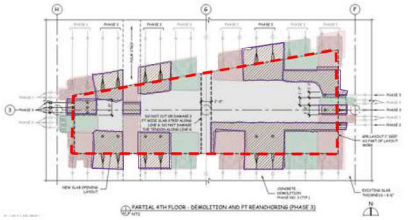
PT Phasing and Demolition Plan *Phase 2*



structural TECHNOLOGIES

Case Study-

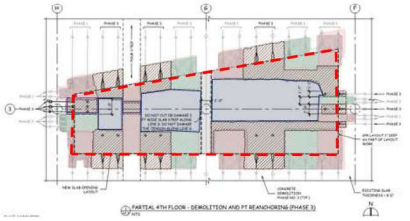
PT Phasing and Demolition Plan – *Phase 3*



structural TECHNOLOGIES

Case Study-

PT Phasing and Demolition Plan *Final Phase 4*



structural TECHNOLOGIES

PT Structure Condition Assessment
Process and Tools

structural TECHNOLOGIES

PT Structure Condition Assessment

1) REVIEW CURRENT CONDITION

- Review PT **design and layout**
- Construction **sequencing**
- Review **exposure** conditions
- **Visual** inspection for **distess**

2) FIELD TESTING

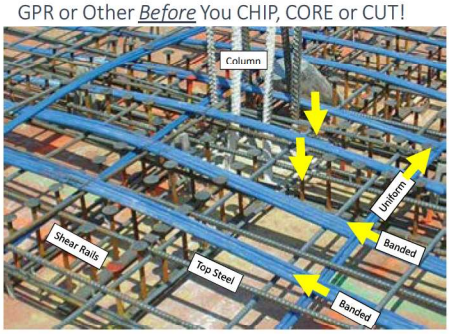
- Non-Destructive Testing **(NDT)**
- Exploratory Destructive Testing **(DT)**

3) LABORATORY TESTING?

- PT system material analysis
- Concrete testing

structural TECHNOLOGIES

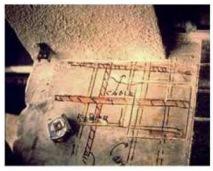
GPR or Other *Before* You CHIP, CORE or CUT!



structural TECHNOLOGIES

Pachometer/GPR Survey

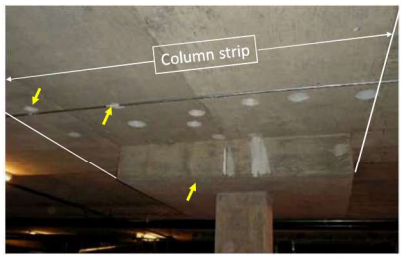
- Identify steel orientation and depth
  - Compare findings to As Builts



NDT limitations – may be difficult differentiating types of embedded steel (PT vs rebar)

structural TECHNOLOGIES

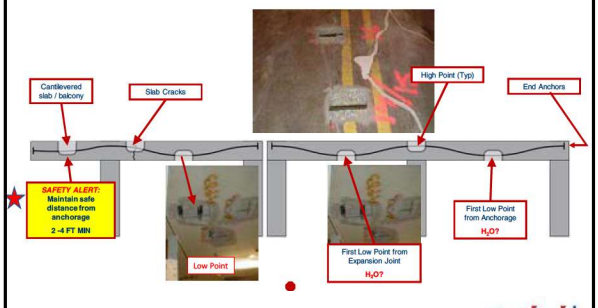
GPR or Other Before Coring!



Permission Not Forgiveness Rule!

structural TECHNOLOGIES

Typical *High* and *Low* Point Tendon and Anchor *Inspection* Points



◄PREV ASSESSMENT NEXT►

structural TECHNOLOGIES

Checking Tendon at Low Point for Water

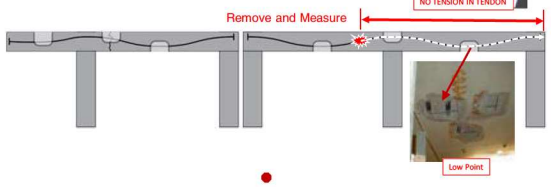
structural TECHNOLOGIES

Is There Tension in the Tendon? Screwdriver Tension Test

- Screwdriver driven between wires
- Used as a qualitative measurement if tendon is tensioned

structural TECHNOLOGIES

Screwdriver Tension Test shows a Break- Where is the break?

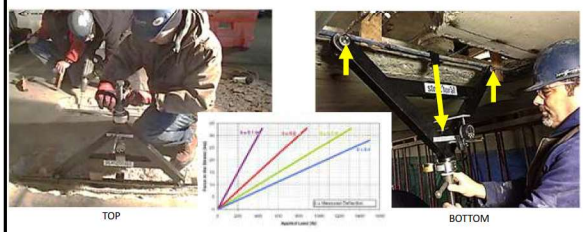


◄PREV ASSESSMENT NEXT►

structural TECHNOLOGIES

In-situ Strand Tension Test – What is the in place tension?

- Applies load to a fixed length of tendon
- Measure effective force in tendon



TOP BOTTOM

structural TECHNOLOGIES

Monostrand Anchor Insp

- Opening anchor pockets to:
  - Inspect wedges for corrosion & seating
  - Inspect anchor for corrosion
  - Anchor Cap inspection?

Anchor before cleaning

Anchor after cleaning

structural TECHNOLOGIES

Half Cell Corrosion Potential Testing on Tendon at Anchor

- Estimates the electrical corrosion potential
- Gauges Probability of Active Corrosion
- ASTM C876-80

Measured Potential* (mV/CSE*)	Probability of Corrosion Activity
> -200	Less than 10%
-200 to -350	Uncertain
< -350	More than 90%

* CSE= Copper Sulfate Electrode

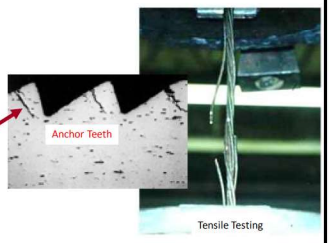
structural TECHNOLOGIES

Laboratory Testing Techniques

REVIEW → TESTING → ADVANCED TESTING

Testing of PT Components

- Corrosion/ pitting visual classification
- Hydrogen embrittlement of tendon?
- Analyze metal components with SEM microscopic investigation
- Grease / inspection testing
- Tensile testing of tendon



Tensile Testing

structural TECHNOLOGIES

PT Structure Safety Considerations

structural TECHNOLOGIES

Post Tension *SAFETY CONSIDERATIONS*

During stressing or de-tensioning process, field investigation and repairs

STORED ENERGY IN A STRESSED TENDON

structural TECHNOLOGIES

Strand Blowout at Anchorage Zones

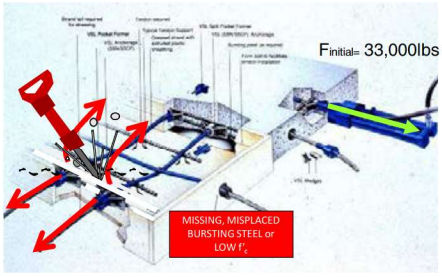
Common Causes:

- Inadequate/misplaced bursting steel
- Low strength concrete
- Concrete voids in anchorage zone
- Chipping behind the anchor

structural TECHNOLOGIES

Post Tension *SAFETY CONSIDERATIONS*

During stressing or de-tensioning process, field investigation and repairs



structural TECHNOLOGIES

Post Tension *SAFETY CONSIDERATIONS*

During stressing or de-tensioning process, field investigation and repairs

Post Tension *SAFETY CONSIDERATIONS*

During stressing or de-tensioning process, field investigation and repairs

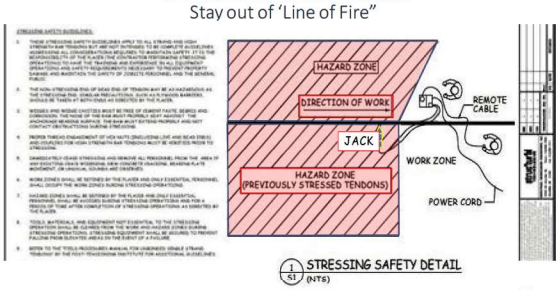
structural TECHNOLOGIES

structural TECHNOLOGIES

Post Tension Safety Considerations

STRESSING SAFETY GUIDELINES

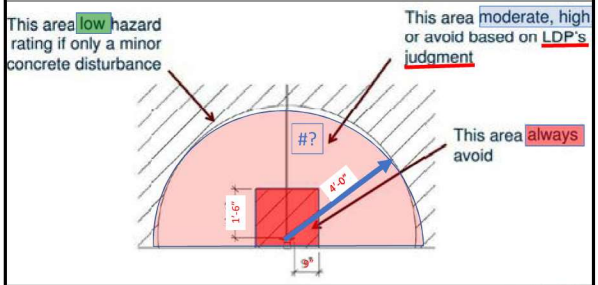
Stay out of 'Line of Fire"



structural TECHNOLOGIES

Post Tension Safety Considerations

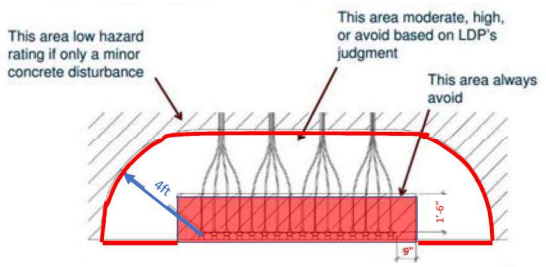
CONCRETE REMOVAL SAFETY GUIDELINES -Stay out of 'Line of Fire"



structural TECHNOLOGIES

Post Tension Safety Considerations

CONCRETE REMOVAL SAFETY GUIDELINES -Stay out of 'Line of Fire"



structural TECHNOLOGIES

Basics of Post-Tensioning

Grouted PT systems

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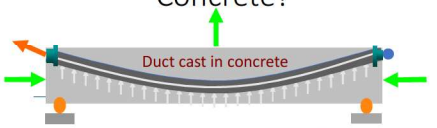
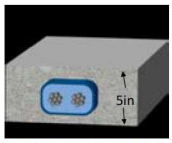
What is Bonded Post Tensioned Concrete?





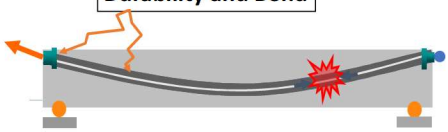
Bare strand in oval slab duct

Bare strand in beam duct

structural TECHNOLOGIES

Why Bonded PT Systems?

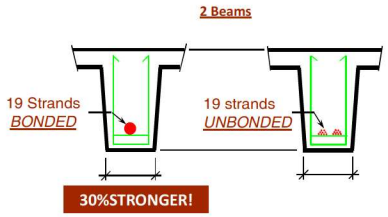
Durability and Bond



structural TECHNOLOGIES

Why Bonded PT Beam Systems?

Increased Strength for Same Amount of PT Strands



structural TECHNOLOGIES

Why Bonded PT Slab Systems? Notice anything missing?

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Why Bonded PT Systems? No top steel

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Thank You!

Any Questions?

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