American Concrete Institute®
Advancing concrete knowledge

FRP Strengthening of Concrete Structures

ACI Spring 2011 Convention
April 3 - 7, Tampa, FL

ACI WEB SESSIONS

ACI Web Sessions

The audio for this web session will begin momentarily and will play in its entirety along with the slides.

However, if you wish to skip to the next speaker, use the scroll bar at left to locate the speaker's first slide (indicated by the icon in the bottom right corner of slides 10, 44, and 62). Click on the thumbnail for the slide to begin the audio for that portion of the presentation.

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ACI Web Sessions

ACI is bringing you this Web Session in keeping with its motto of "Advancing Concrete Knowledge." The ideas expressed, however, are those of the speakers and do not necessarily reflect the views of ACI or its committees.

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ACI Web Sessions are recorded at ACI conventions and other concrete industry events. At regular intervals, a new set of presentations can be viewed on ACI's website free of charge.

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ACI Conventions

ACI conventions provide a forum for networking, learning the latest in concrete technology and practices, renewing old friendships, and making new ones. At each of ACI's two annual conventions, technical and educational committees meet to develop the standards, reports, and other documents necessary to keep abreast of the ever-changing world of concrete technology.

With over 1,300 delegates attending each convention, there is ample opportunity to meet and talk individually with some of the most prominent persons in the field of concrete technology. For more information about ACI conventions, visit www.aciconvention.org.

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Fall 2011 Seminars

These seminars, cosponsored by ACI and the Portland Cement Association (PCA), will cover all the major changes in the new edition of the **318-11 Building Code**.

DATE	LOCATION	DATE	LOCATION
September 13	Chicago, IL	November 3	Charlotte, NC
September 27	Philadelphia, PA	November 8	Boston, MA
September 29	Houston, TX	November 10	Detroit, MI
October 4	Seattle, WA	November 15	Des Moines, IA
October 6	Los Angeles, CA	November 17	Portland, OR
October 11	New York, NY	November 29	Denver, CO
October 13	Minneapolis, MN	December 1	Phoenix, AZ
October 20	Cincinnati, OH	December 6	Atlanta, GA
October 25	New Brunswick, NJ	December 8	Washington, DC
October 27	St. Louis, MO	December 13	Dallas, TX
November 1	Orlando, FL	December 15	San Francisco, CA

For more information, visit ACI seminars.

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This ACI Web Session includes 3 speakers presenting at the ACI spring convention held in Tampa, FL April 3 – 7, 2011.

Additional presentations will be made available in future ACI Web Sessions.

Please enjoy the presentations.

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FRP Strengthening of Concrete Structures

ACI Spring 2011 Convention
April 3 - 7, Tampa, FL

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Scott T. Smith, Assistant Professor in the Department of Civil Engineering at The University of Hong Kong, China. He is an Associate Member of ACI Committee 440, Fiber-Reinforced Polymer Reinforcement.

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Fiber-Reinforced Polymer Reinforcement for Concrete Structures

10th International Symposium

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Strength and Deflection Enhancement of RC Slabs with Anchored FRP Strengthening

S.T. Smith[1], S.H. Hu[1], S.J. Kim[2] and R. Seracino[3]

[1] The University of Hong Kong, China
[2] Industrial Composite Contractors (ICC), Australia (formerly of affiliation 1)
[3] North Carolina State University, USA

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Scope of Presentation

- Background Information
- Experimental Details
- Experimental Results
- Analytical Modelling
- Conclusions

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Background Information

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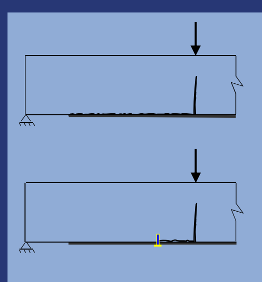
Problem Definition



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Current Situation

- We are seeing more and more applications of anchors to externally bonded FRP plates
- Plentiful design guidance available (i.e. CECS, Concrete Society, SA, ACI, fib, ISIS, CSA, JSCE, CNR etc) but limited anchorage guidance
- Further proof of anchorage concept required

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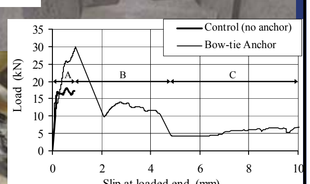
FRP Anchors and Joint Tests



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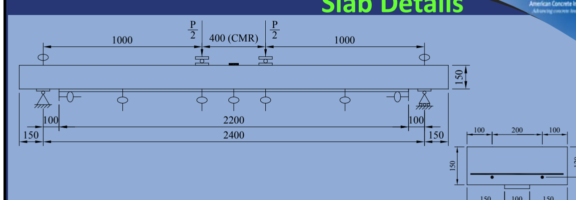
Slab Details



Concrete: 51.7 MPa (7498 psi) to 56.8 MPa (8223 psi)

Steel Reo: Yield Stress=566 MPa (82 ksi), E=198 GPa (28,717 ksi)

FRP: carbon fibre sheet, 0.166 mm (0.0065 in.) thickness
coupon: strain=14,674 $\mu\varepsilon$, strength=3,163 MPa (459 ksi), E=239 GPa (34,664 ksi)

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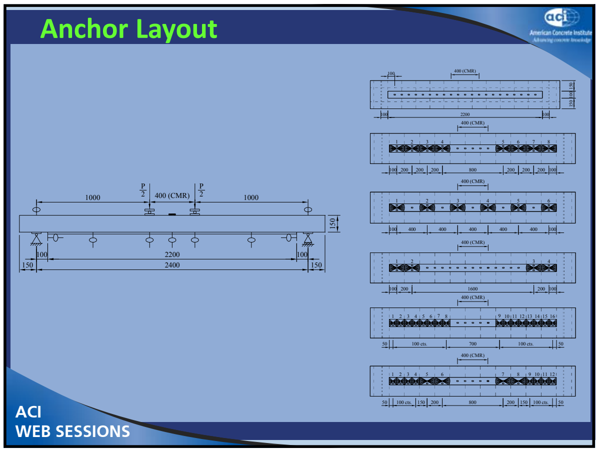
Anchor Layout
1000
400 (CMR)
1000
2200
2400
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FRP Anchor and Sheet Installation
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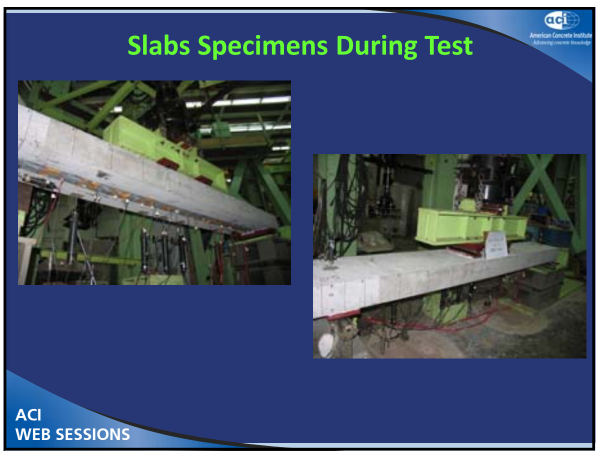
Slabs Specimens During Test
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Experimental Results
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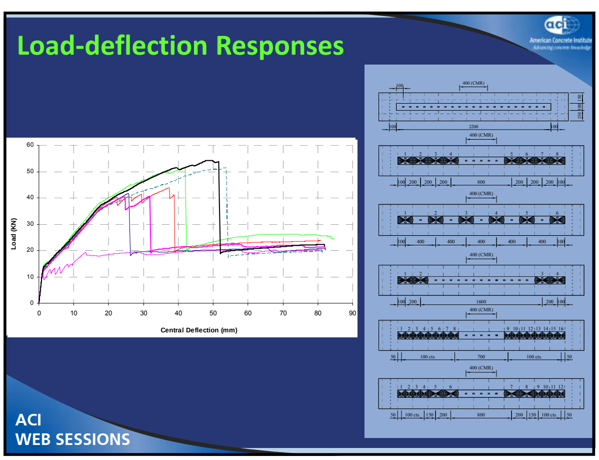
Load-deflection Responses
Load (KN)
Central Deflection (mm)
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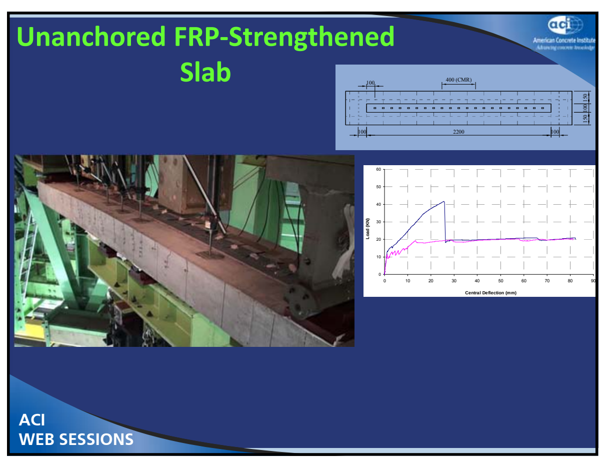
Unanchored FRP-Strengthened Slab
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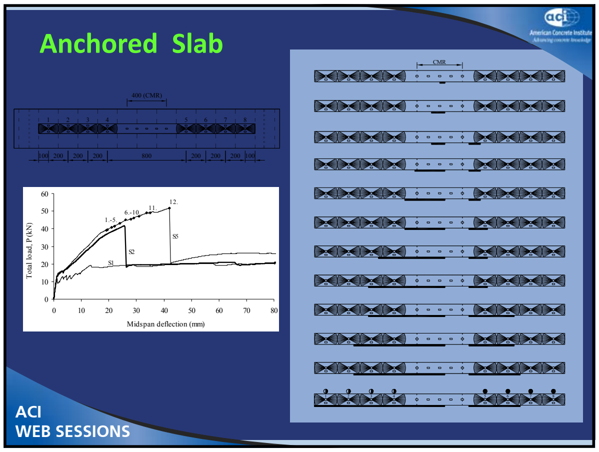
Anchored Slab
400 (CMR)
CMR
Total load, P (kN)
Midspan deflection (mm)
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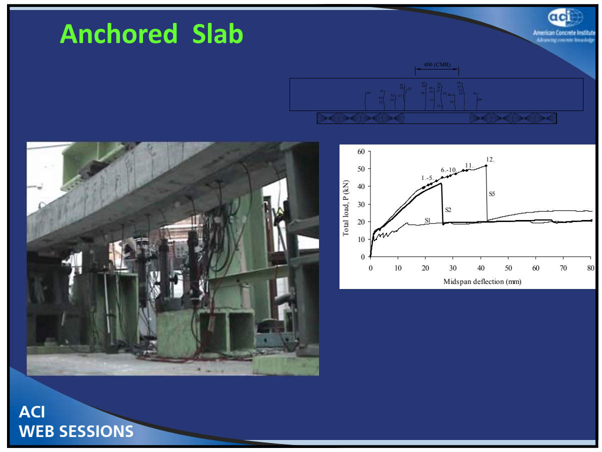
Anchored Slab
400 (CMR)
Total load, P (kN)
Midspan deflection (mm)
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Failure Modes
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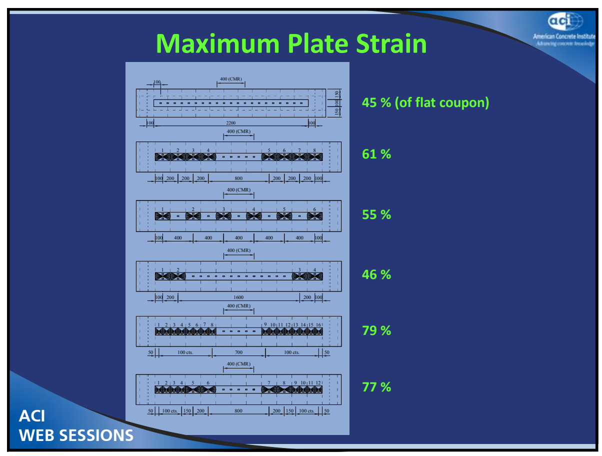
Maximum Plate Strain
45 % (of flat coupon)
61 %
55 %
46 %
79 %
77 %
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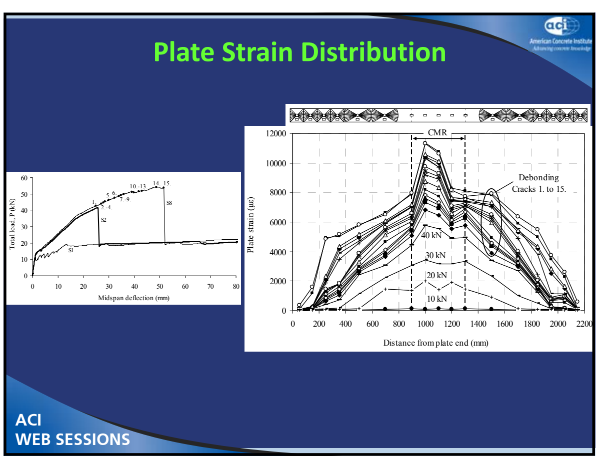
Plate Strain Distribution
Total load, P (kN)
Midspan deflection (mm)
CMR
Debonding Cracks 1. to 15.
40 kN
30 kN
20 kN
10 kN
Plate strain (με)
Distance from plate end (mm)
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WEB SESSIONS

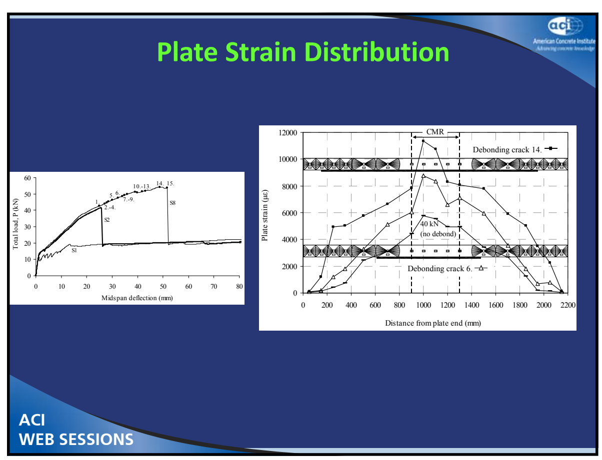
Plate Strain Distribution
Total load, P (kN)
Midspan deflection (mm)
CMR
Debonding crack 14.
40 kN (no debond)
Debonding crack 6.
Plate strain (με)
Distance from plate end (mm)
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Analytical Modelling

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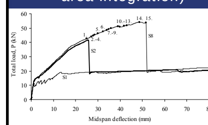
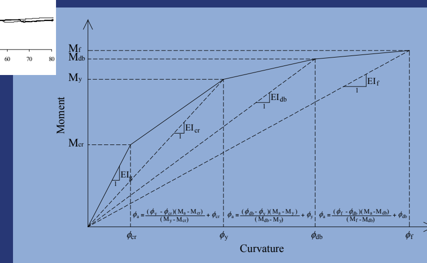
Idealised Behaviour

- Closed-form solutions (assumed M-k relationship + moment area integration)





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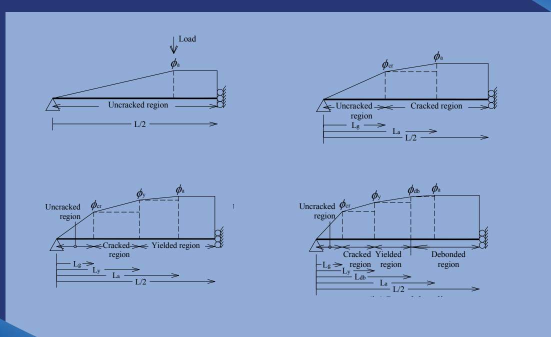
Curvature Distribution



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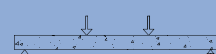
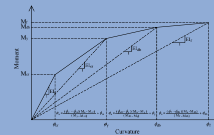
Analytical Solution





$(0 < M_a < M_{cr})$

$$\Delta_{mid} = \int_0^{L/2} x\phi(x)dx$$

$(M_{cr} < M_a < M_y)$

$$\Delta_{mid} = \int_0^{L_g} x\phi(x)dx + \int_{L_g}^{L/2} x\phi(x)dx$$

$(M_y < M_a < M_{db})$

$$\Delta_{mid} = \int_0^{L_g} x\phi(x)dx + \int_{L_g}^{L_y} x\phi(x)dx + \int_{L_y}^{L/2} x\phi(x)dx$$

$(M_{db} < M_a < M_f)$

$$\Delta_{mid} = \int_0^{L_g} x\phi(x)dx + \int_{L_g}^{L_y} x\phi(x)dx + \int_{L_y}^{L_{db}} x\phi(x)dx + \int_{L_{db}}^{L/2} x\phi(x)dx$$

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Important Sectional Properties

- Concrete Cracking: $f_t = 0.6\sqrt{f'_c}$ → Cal ϕ_{cr} and M_{cr}
  $M_{cr} = Zf_t$ (Z = uncracked section modulus)
- Steel Yielding: $\sigma_{reo} = f_y$ → Cal ϕ_y and M_y
- FRP Debonding: $\sigma_{dbic} = \alpha\beta_P\beta_L\sqrt{\frac{E_p\sqrt{f'_c}}{t_p}}$ → Cal ϕ_{db} and M_{db}

(Teng et al. 2003, ACI 440.2R 2008)

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FRP Anchorage Modelling Strategy

- Maintain full interaction in strain
- Strain to stress: k = shear transfer coefficient

$$\sigma_a = E_{frp}\varepsilon_a \qquad 0 < \varepsilon_a \le \varepsilon_{db}$$

$$\sigma_a = \frac{(kE_{frp}\varepsilon_{frp} - \sigma_{db})}{(\varepsilon_{frp} - \varepsilon_{db})}(\varepsilon_a - \varepsilon_{db}) + \sigma_{db} \qquad \varepsilon_{db} < \varepsilon_a \le \varepsilon_{frp}$$

$$\sigma_{dbic} = \alpha\beta_P\beta_L\sqrt{\frac{E_p\sqrt{f'_c}}{t_p}}$$

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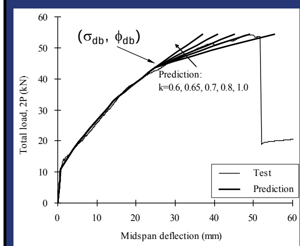
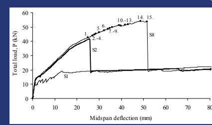
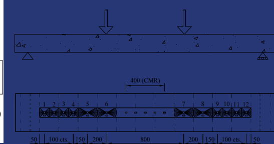
Anchored Slab







- Debonding to failure: fit to test results

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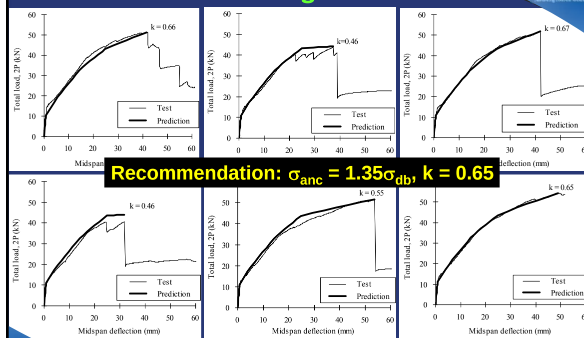
Modelling Results



Recommendation: $\sigma_{anc} = 1.35\sigma_{db}$, k = 0.65

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Conclusions

- Experiments show that FRP anchors can
  - increase strain capacity of plate from 45 to 79 %
  - increase peak load by 30 % (above unanchored control)
  - increase peak deflection by 110 % (above unanchored control)
- Analysis can:
  - can capture load-deflection response
  - recommendation key values for design

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Acknowledgements

- General Research Fund Grant HKU 716308E of Hong Kong Research Grants Council
- Messers Huawen ZHANG (PhD candidate), Jiaqi YANG (MPhil candidate), Kin Lung Jason LI (2009-10 undergraduate final year project student), and the LG laboratory technicians, The University of Hong Kong
- Dr Jacob SCHMIDT, Technical University of Denmark

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谢谢_

Xie Xie

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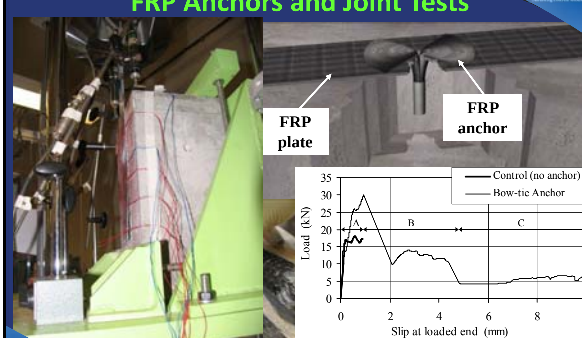
FRP Anchors and Joint Tests



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FIBER-REINFORCED POLYMER REINFORCEMENT FOR CONCRETE STRUCTURES FRP-RCS10
April 2-4, 2011 - Tampa, Florida, USA

NSM FRP STRIPS SHEAR STRENGTH CONTRIBUTION TO A RC BEAM: A DESIGN PROCEDURE

Vincenzo Bianco [1a], Giorgio Monti [1b] and J.A.O. Barros [2c]

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[2] Dept. of Civil Engineering, University of Minho, Guimarães, Portugal

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SIMPLIFIED DESIGN PROCEDURE FOR PRACTITIONERS

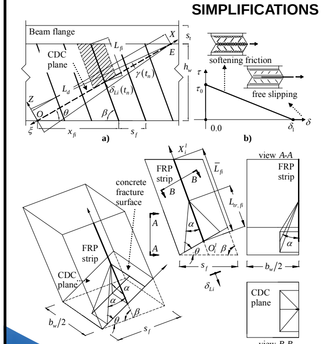
The *proposed procedure* has to be:

- ***Mechanics-based***, *i.e.* it has to fulfil equilibrium, kinematic compatibility and constitutive laws of the materials involved;
- ***Simple to apply***, consistently with the informatics tools each structural engineer has at his disposal nowadays.

The *proposed procedure* is based on the evaluation of:

1) The ***constitutive law*** $V_{fi}\left(\bar{L}_{fi};\delta_{Li}\right)$ of the average-available-bond-length NSM FRP strip effectively crossing the CDC;
2) The ***maximum effective capacity*** $V_{fi,eff}^{\max}$ that the average-available-bond-length NSM FRP strip can attain during the loading process of the strengthened beam.

SIMPLIFIED APPROACH FOR PRACTITIONERS: SIMPLIFICATIONS INTRODUCED



1. Determination of the ***average system*** composed of the average available bond length strip Near-Surface-Mounted on the relevant prism of surrounding concrete;
2. ***Simplified local bond stress-slip relationship*** *i.e.* characterized by the only phases of "softening friction" and "free slipping";
3. ***Semi-pyramidal*** concrete fracture surface, instead of semi-conical.

SIMPLIFIED APPROACH FOR PRACTITIONERS: FLOW CHART

Input Parameters
$h_w;b_w;\alpha;f_{cm};s_f;\beta;f_{fu};E_f;a_f;b_f;\tau_0;\delta_1;\dot{\delta}_{Li};\theta$

↓

Evaluation of the average value of the available bond length and the minimum number of strips crossing the CDC
$\bar{L}_{fi}=f\left(h_w;\theta;\beta;s_f\right);N_{f,int}^{l}$

↓

Evaluation of the bond constitutive law of the average length NSM strip
$V_{fi}^{bd}\left(\bar{L}_{fi};\delta_{Li}\right)=f\left(\tau_0;\delta_1;a_f;b_f;E_f;f_{cm};s_f;b_w\right)$

↓

Evaluation of the comprehensive constitutive law of the average length strip
$V_{fi}\left(\bar{L}_{fi};\delta_{Li}\right)=f\left[V_{fi}^{bd}\left(\bar{L}_{fi};\delta_{Li}\right);f_{cm};s_f;b_w;f_{fu};\alpha\right]$

↓

Evaluation of the maximum effective capacity of the average NSM FRP strip
$V_{fi,eff}^{\max}$

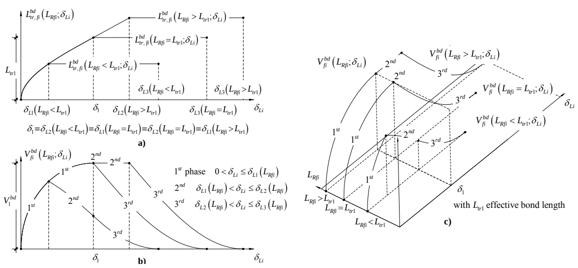
↓

Application of the Shear Formula
$V_f^{\max}=2\cdot N_{f,int}^{l}\cdot V_{fi,eff}^{\max}\cdot\sin\beta$

BOND-BASED CONSTITUTIVE LAW OF A NSM FRP STRIP

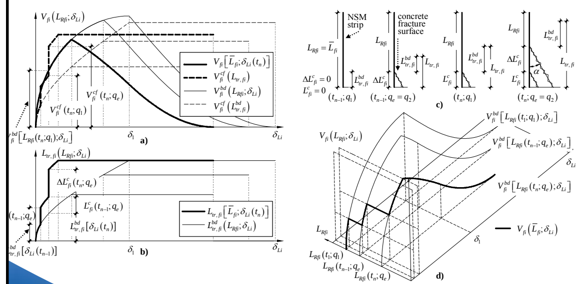
Bi-dimensional representation

Tri-dimensional representation



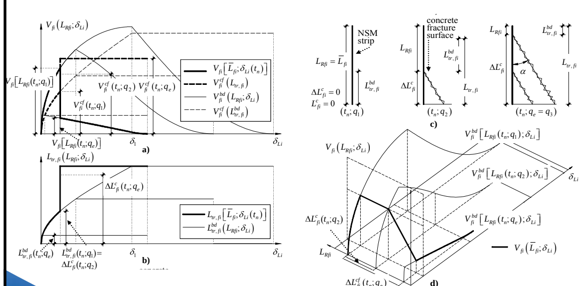
COMPREHENSIVE CONSTITUTIVE LAW OF A NSM FRP STRIP

Superficial concrete fracture

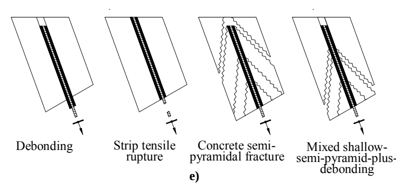


COMPREHENSIVE CONSTITUTIVE LAW OF A NSM FRP STRIP

Deep concrete fracture



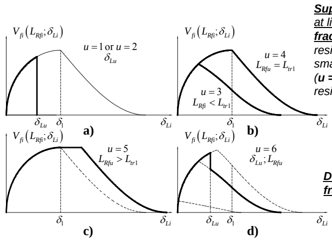
ULTIMATE CONFIGURATIONS ASSUMED BY THE AVERAGE AVAILABLE BOND LENGTH STRIP



COMPREHENSIVE CONTITUTIVE LAW OF A NSM FRP: POSSIBLE CASES

***Strip Rupture** (**u = 1**) with or without an initial concrete fracture, or **concrete fracture up to the free end** (**u = 2**)*

***Superficial** (or absent, at limit) **concrete fracture** and last resisting bond length smaller (**u = 3**) or equal (**u = 4**) to the effective resisting bond length.*



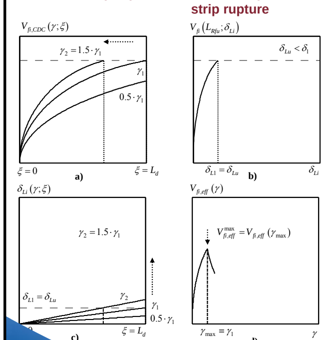
***Superficial** (or absent) **concrete fracture** and last value of the resisting bond length larger (**u = 5**) than the effective resisting bond length.*

***Deep concrete fracture** (**u = 6**)*

Whatever the case, among these above, **the analytical equations are exactly those of the bond-based behavior**. The only problem is determining correctly the value of the resisting bond length following concrete fracture and/or the value of the imposed end slip in correspondence of which peak is attained.

EVALUATION OF THE MAXIMUM EFFECTIVE CAPACITY:

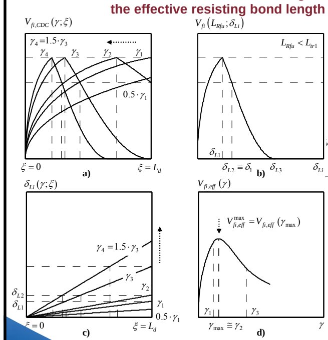
case of either (u=1) concrete fracture up to the free extremity or (u=2) strip rupture



$$V_{fl,eff}^{max} = V_{fl,eff}(\gamma_{max}) = \frac{1}{L_d}\left\{A_1 \cdot C_1^{cf} \cdot L_d^2 \cdot \gamma_{max} + \frac{A_2 \cdot C_2^{cf}}{2 \cdot A_3 \cdot \gamma_{max}} \cdot \left[\arcsin(1 - A_3 \cdot \gamma_{max} \cdot L_d) + (1 - A_3 \cdot \gamma_{max} \cdot L_d) \cdot \sqrt{1 - (1 - A_3 \cdot \gamma_{max} \cdot L_d)^2} - \frac{\pi}{2}\right]\right\}$$

$$\gamma_{max} = \gamma_1 = \frac{2 \cdot \delta_{Lu}}{L_d \cdot \sin(\theta + \beta)}$$

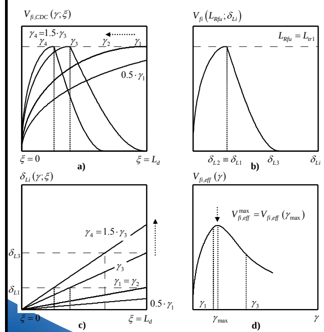
EVALUATION OF THE MAXIMUM EFFECTIVE CAPACITY: shallow concrete fracture and ultimate resisting bond length smaller than the effective resisting bond length (u=3)



$$V_{fi,eff}^{max} = \frac{1}{L_d}\cdot\left\{\left[A_1\cdot\left(C_1^{sf}-C_1\right)\cdot\left(\frac{2\cdot\delta_{L1}}{\sin(\theta+\beta)}\right)^2+\left(C_2^{sf}+C_2\right)\cdot\frac{A_2\cdot\Phi_1(\delta_{L1})}{2\cdot A_3}-\frac{A_2\cdot C_2^{sf}\cdot\pi}{4\cdot A_3}-\frac{2\cdot A_2\cdot C_1\cdot\delta_{L1}}{\sin(\theta+\beta)}\right]\cdot\frac{1}{\gamma_{max}}-\frac{A_2\cdot C_2}{2\cdot A_3\cdot\gamma_{max}}\cdot\left[\arcsin(1-A_3\cdot\gamma_{max}\cdot L_d)+(1-A_3\cdot\gamma_{max}\cdot L_d)\cdot\sqrt{1-(1-A_3\cdot\gamma_{max}\cdot L_d)^2}\right]+A_2\cdot C_1\cdot L_d+A_1\cdot C_1\cdot\gamma_{max}\cdot L_d^2\right\}$$

$$\gamma_{max} = \gamma_2 = \frac{2\cdot\delta_{L2}\left(L_{Rfu}\right)}{L_d\cdot\sin(\theta+\beta)}$$

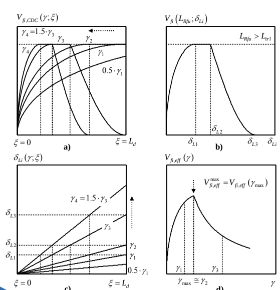
EVALUATION OF THE MAXIMUM EFFECTIVE CAPACITY: shallow concrete fracture and ultimate resisting bond length equal to the effective resisting bond length (u=4)



$$V_{fi,eff}^{max} = \frac{1}{L_d}\cdot\left\{A_1\cdot C_1^{sf}\cdot L_d^2\cdot\gamma_{max}+\frac{A_2\cdot C_2^{sf}}{2\cdot A_3\cdot\gamma_{max}}\cdot\left[\arcsin(1-A_3\cdot\gamma_{max}\cdot L_d)+(1-A_3\cdot\gamma_{max}\cdot L_d)\cdot\sqrt{1-(1-A_3\cdot\gamma_{max}\cdot L_d)^2}-\frac{\pi}{2}\right]\right\}$$

$$\gamma_{max} = \gamma_1 = \frac{2\cdot\delta_1}{L_d\cdot\sin(\theta+\beta)}$$

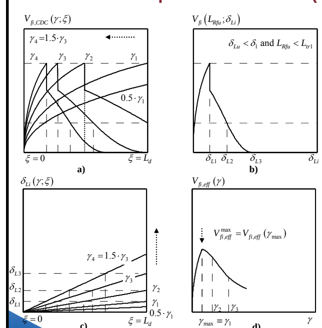
EVALUATION OF THE MAXIMUM EFFECTIVE CAPACITY: shallow concrete fracture and ultimate resisting bond length larger than the effective resisting bond length (u=5)



$$V_{fi,eff}^{max} = \frac{1}{L_d}\cdot\left\{\left[A_1\cdot C_1^{sf}\cdot\left(\frac{2\cdot\delta_1}{\sin(\theta+\beta)}\right)^2+\frac{C_2^{sf}\cdot A_2\cdot\Phi_1(\delta_1)}{2\cdot A_3}-\frac{A_2\cdot C_2^{sf}\cdot\pi}{4\cdot A_3}\right]\cdot\frac{1}{\gamma_{max}}+V_{f1}^{bd}\cdot\left(L_d-\frac{2\cdot\delta_1}{\gamma_{max}\cdot\sin(\theta+\beta)}\right)\right\}$$

$$\gamma_{max} = \gamma_2 = \frac{2\cdot\delta_{L2}\left(L_{Rfu}\right)}{L_d\cdot\sin(\theta+\beta)}$$

EVALUATION OF THE MAXIMUM EFFECTIVE CAPACITY: deep concrete fracture (u=6)



$$V_{fi,eff}^{max} = \max\left\{V_{fi,eff}^{max1};V_{fi,eff}^{max2}\right\}$$

$$V_{fi,eff}^{max1} = V_{fi,eff}(\gamma_{max1}) = \frac{1}{L_d}\cdot\left\{A_1\cdot C_1^{sf}\cdot L_d^2\cdot\gamma_{max1}+\frac{A_2\cdot C_2^{sf}}{2\cdot A_3\cdot\gamma_{max1}}\cdot\left[\arcsin(1-A_3\cdot\gamma_{max1}\cdot L_d)+(1-A_3\cdot\gamma_{max1}\cdot L_d)\cdot\sqrt{1-(1-A_3\cdot\gamma_{max1}\cdot L_d)^2}-\frac{\pi}{2}\right]\right\}$$

$$\gamma_{max1} = \gamma_1 = \frac{2\cdot\delta_{Lu}}{L_d\cdot\sin(\theta+\beta)}$$

$$V_{fi,eff}^{max2} = V_{fi,eff}(\gamma_{max2}) = \frac{1}{L_d}\cdot\left\{\left[A_1\cdot\left(C_1^{sf}-C_1\right)\cdot\left(\frac{2\cdot\delta_{Lu}}{\sin(\theta+\beta)}\right)^2+\left(C_2^{sf}+C_2\right)\cdot\frac{A_2\cdot\Phi_1(\delta_{Lu})}{2\cdot A_3}-\frac{A_2\cdot C_2^{sf}\cdot\pi}{4\cdot A_3}+-\frac{2\cdot A_2\cdot C_1\cdot\delta_{Lu}}{\sin(\theta+\beta)}\right]\cdot\frac{1}{\gamma_{max2}}+-\frac{A_2\cdot C_2}{2\cdot A_3\cdot\gamma_{max2}}\cdot\left[\arcsin(1-A_3\cdot\gamma_{max2}\cdot L_d)+(1-A_3\cdot\gamma_{max2}\cdot L_d)\cdot\sqrt{1-(1-A_3\cdot\gamma_{max2}\cdot L_d)^2}\right]+A_2\cdot C_1\cdot L_d+A_1\cdot C_1\cdot\gamma_{max2}\cdot L_d^2\right\}$$

$$\gamma_{max2} = \gamma_2 = \frac{2\cdot\delta_{L2}\left(L_{Rfu}\right)}{L_d\cdot\sin(\theta+\beta)}$$

SIMPLIFIED DESIGN PROCEDURE: APPRAISAL

Table 1 — Values of the parameters characterizing the beams adopted to appraise the formulation proposed (1 *mm* = 0.0394 *in* - 1 *N* = 0.2248 *lb*).

Beam Label	θ^{exp} °	β °	z_f mm(in)	V_{f1}^{num} kN	V_{f2}^{num} kN	V_{f3}^{num} kN	V_f^{exp} kN(kip)	$\bar{L}_f$ mm(in)	u	V_f kN(kip)
2S-3LV	40	90	267(10.52)	18.53	6.46	55.33	**22.20(4.99)**	75.96(2.99)	3	**10.77(2.42)**
2S-5LV	40	90	160(6.30)	52.33	26.42	55.34	**25.20(5.66)**	82.87(3.27)	6	**30.97(6.96)**
2S-8LV	36	90	100(3.94)	68.58	58.88	64.33	**48.60(10.93)**	77.34(3.05)	3	**29.59(6.65)**
2S-3LI45	45	45	367(14.46)	35.10	15.41	45.73	**29.40(6.61)**	164.75(6.49)	3	**23.44(5.27)**
2S-5LI45	45	45	220(8.67)	46.11	49.14	45.74	**41.40 (9.31)**	134.35(5.29)	3	**23.19(5.21)**
2S-8LI45	36	45	138(5.44)	75.89	79.71	78.73	**40.20*(9.04)**	106.73(4.21)	6	**59.55(13.39)**
2S-3LI60	33	60	325(12.81)	50.69	18.90	51.68	**35.40(7.96)**	169.16(6.66)	3	**30.74(6.91)**
2S-5LI60	36	60	195(7.68)	36.37	36.59	48.55	**46.20(10.39)**	77.27(3.04)	6	**22.27(5.01)**
2S-7LI60	33	60	139(5.48)	52.98	63.07	67.58	**54.60(12.27)**	91.05(3.59)	6	**60.80(13.67)**

All beams have existing steel stirrups ⌀6/300

* This experimental value was affected by some disturbance

The ratio V_f / V_f^{exp} presents mean value of 0.85 and standard deviation of 0.36

FUTHER (DESIRABLE) DEVELOPMENTS

FROM THE RESEARCHERS' POINT OF VIEW

1) Analytical equations providing the values of the parameters defining the local bond stress-slip relationship as function of chemical properties of both 1) concrete and 2) adhesive and 3) adhesive layer's thickness;
2) Interaction with existing steel stirrups.

FROM THE PRACTITIONERS' POINT OF VIEW

1) More simple equations;
2) Closed form *i.e.* absence of iteration to determine the strip's constitutive law

Thank you for your attention

ACI WEB SESSIONS

NSM FRP strips shear strength contribution to a RC beam: a design procedure

FRP-RCS10 - Tampa - Florida 2-4 Aprile 2011

Grahme Williams is a practicing bridge engineer working for Sinclair Knight Merz (SKM) in Melbourne, Australia. His particular area of interest is in the use of CFRP strengthening systems having been involved with a range of activities including laboratory investigations, field monitoring of repaired structures, design and optimization of systems and application to in-service bridges.

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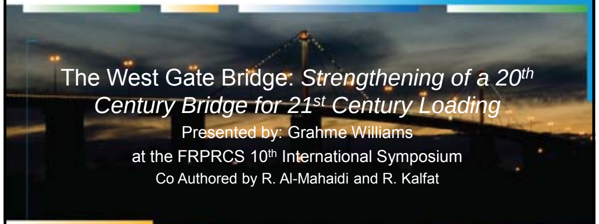
Monash-CityLink-West Gate upgrade | West Gate Bridge



The West Gate Bridge: *Strengthening of a 20th Century Bridge for 21st Century Loading*

Presented by: Grahme Williams

at the FRPRCS 10th International Symposium

Co Authored by R. Al-Mahaidi and R. Kalfat

flint neill | John Holland | SKM | vicroads

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Introduction

Agenda:

- Project Overview
- Design Considerations
  - Actions
  - Constraints
  - Opportunities
- Review of Construction
- Testing and Inspection
- Factors Influencing Installation
- Closing Comments

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Project Overview – General Arrangement

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Project Overview – Viaduct Components

- Pre-cast & in-situ deck slab
- Post-tensioned precast cantilevers
- Pre-cast segments with in-situ joints
- Hinged piers

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Modelling Phase

Construction Stages

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Design Considerations - General

- **ACI 440.2R by the American Concrete Institute**
- **FIB 14 by the Fédération International du Béton, or European Concrete Task**
- **Technical Report No. 55 by the UK Concrete Society**

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Design Considerations – Design Action

For Flexure:

- Bond Strength able to be developed
- Available bond area

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Design Considerations – Design Action

For Shear:

The effective strain in the FRP, ε_{fse}

(i) $\varepsilon_{fd} / 2$

(ii) $0.64 \cdot \sqrt{\dfrac{f_{ctm}}{E_{fd} \cdot t_f}}$

(iii) 0.004

where:

ε_{fd} = design ultimate strain capacity of FRP

f_{ctm} = tensile strength of the concrete (N/mm^2)

E_{fd} = design tensile modulus of the FRP (N/mm^2)

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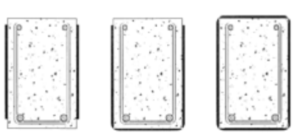
Design Considerations – Design Action

Typical Arrangements for FRP Shear Anchorage



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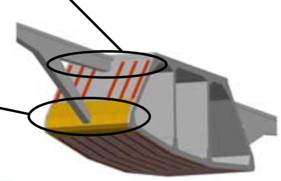
Design Considerations – Design Action

Further Investigation was required on FRP Termination Details

FRP End Termination detail at Deck Slab / Web Junction

FRP End Termination detail at Box Girder Soffit / Web Intersection



Note: Further discussion in Manuscript E9

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Design Considerations

Bond Strength

- Min concrete compressive strength of 20 Mpa (2.9 ksi)
- Based on traditional structures with lower grade concrete (typically 25-35 MPa) (3.5-4.5 ksi)
- Original strengthening materials
  - Glass fiber typically lower modulus than CF
  - Carbon fiber typically thin, 165 GPa (24,000 ksi) modulus
- Capable of achieving pull-off strength values of 1.5 Mpa (220 psi) (min)

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Design Considerations

Selection of Materials

- Grade
  - Achievable bond strength
  - Governed by detailing (which was tested and verified)
  - Available materials
- Practicality of application
  - Stiffness - ability to match surface
  - Width – ability to achieve a sound bond
- Matching existing (West Viaduct)
  - Strain compatibility

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Design Considerations

Surface Preparation

- VicRoads Specification of 0.5 to 1.0 mm (0.02-0.04 in) amplitude
- Similar to 60-grit sandpaper
- Several methods trialled and a representative area agreed by all parties
- Ultimately achieved a roughened surface with exposed aggregate and a relatively flat/uniform profile

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Access

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Surface Preparation

- Abrasive blasting
- UHP Water blasting
- Vacuum blasting

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Repairs to Existing Structure

- Crack injection
- Patch repair

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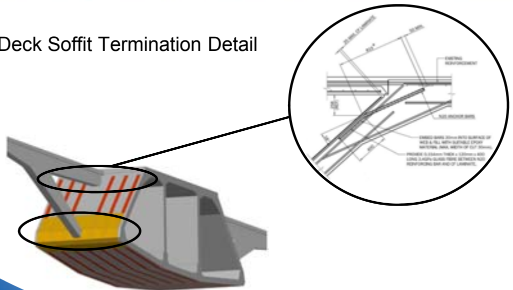
Site Implementation

Deck Soffit Termination Detail



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Site Implementation

Deck Soffit Termination Detail

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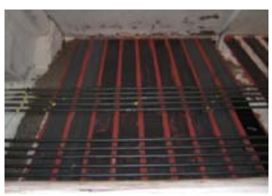
Site Implementation

Deck Soffit Termination Detail



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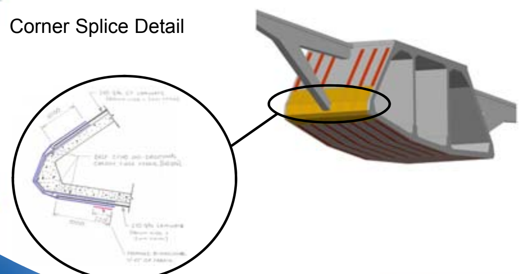
Site Implementation

Corner Splice Detail



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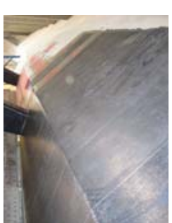
Site Implementation

Corner Splice Detail



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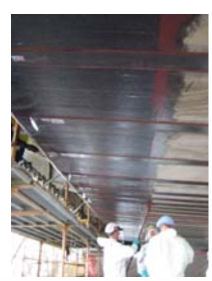
Site Implementation

Corner Splice Detail



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Site Implementation

Corner Splice Detail

Site Implementation

Corner Splice Detail

Site Implementation

Corner Splice Detail

Testing

- Visual inspection
- Drummy testing
- Adhesion testing
- Dry film thickness measurement
- Flatness measurements

Defect Repairs

- Resin injection
- Remove and replace

Treatment of Existing Carbon Fiber

- Application of new fabric over existing fabric
- Adhesion Testing
- Drummy testing
- Fabric removal

Environmental Conditions

- Heating application areas
- Saturant cure rate
- Ambient conditions
  - Rising Temp
  - Dew Point
  - Humidity

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Closing Comments

- To the authors knowledge:
  - The largest bridge of its type in the world to ever be repaired with carbon fibre
  - The largest volume of carbon fibre to be installed
    - 40+ km (25 miles) of mixed grade and size CF laminates
    - 11,000+ m^2 (118,000 ft^2 of CF fabric (including bidirectional)
  - 76,000 litres (20,000 gallons) of epoxy resin

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Questions?

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Concrete Knowledge

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