July 21, 2019 Seminar for HDOT

BFRP-RC Standardization of Design & Materials

FHWA Project: STIC-0004-00A
(Phase 3 - Technology Transfer)

STIC
State Transportation Innovation Councils

FRP-RC Design - Part 4

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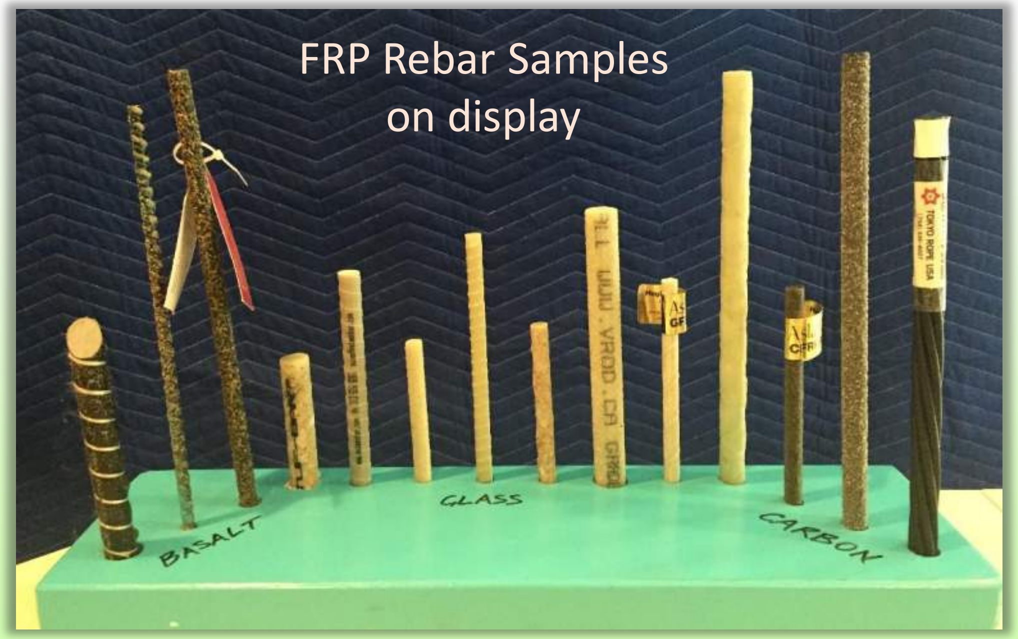
MIAMI

FDOT

Seminar Description

Fiber-reinforced polymer (FRP) materials have emerged as an alternative for producing reinforcing bars for concrete structures. Due to other differences in the physical and mechanical behavior of FRP materials versus steel, unique guidance on the engineering and construction of concrete structures reinforced with FRP bars is necessary.



Learning Objectives

Part 1

- Understand the mechanical properties of FRP bars
- Describe the behavior of FRP bars

Part 2

- Describe the design assumptions
- Describe the use of internal FRP bars for serviceability & durability design including long-term deflection

Part 3

- Describe the flexural/shear/compression and fatigue design procedures of concrete members internally reinforced with FRP bars

Part 4

- Review the procedure for determining the development, splice length, and bends for FRP bars.

Content of the Complete Course

FRP-RC Design - Part 1, (30 min.)

This session will introduce concepts for reinforced concrete design with FRP rebar. Topics will address:

- Materials & Design Specifications;
- Design & Typical Applications;
- FRP Rebar Properties;
- New Developments and Solutions;

FRP-RC Design - Part 2, (45 min.)

This session will introduce Basalt FRP rebar that is being standardized under FHWA funded project ***STIC-0004-00A*** with extended FDOT research under BE694, and provide training on the flexural design of beams, slabs, and columns for:

- Design Assumptions and Material Properties
- Ultimate capacity and rebar development length under strength limit states;
- Crack width, sustained load resistance, and deflection under service limit state;

Content of the Complete Course

FRP-RC Design - Part 3, (45 min.)

This session continues with Basalt FRP rebar from Part 2, covering shear and axial design of columns at the strength limit states for:

- Flexural Behavior and Resistance (Session 3a);
- Shear Behavior and Resistance of beams and slabs (Session 3b);
- Axial Behavior of columns & Combined axial and flexure Resistance (Session 3c).

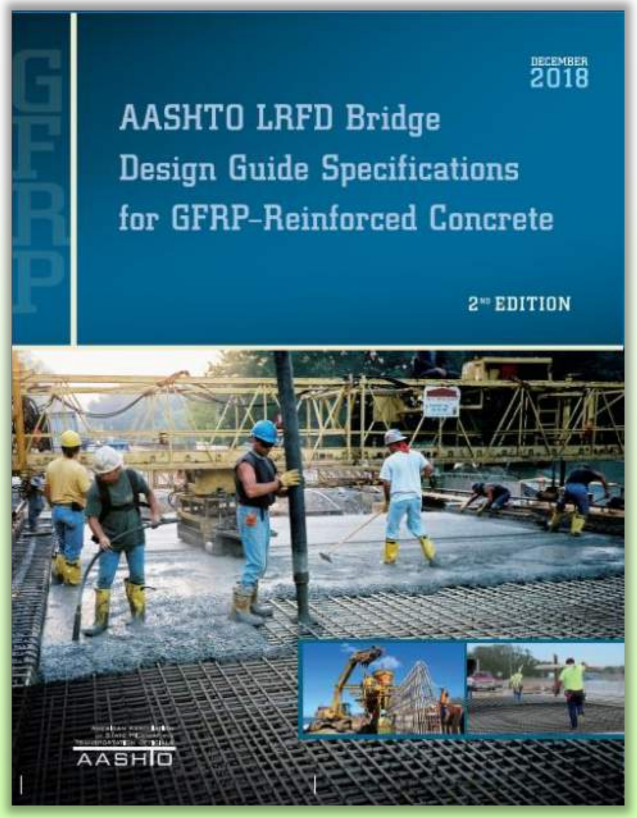
FRP-RC Design - Part 4, (30 min.)

This session continues with FRP rebar from Part 3, covering detailing and plans preparation:

- Fatigue resistance under the Fatigue limit state
- Minimum Shrinkage and Temperature Reinforcing
- Bar Bends and Splicing

Session 4: Fatigue Design Resistance

1. **AASHTO-GGS2**: "LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridges *2nd Edition (2018)*



Session 4: Fatigue Design

Fatigue Load Factors and Load Combinations:

- ***AASHTO-GGS2*** uses a modified load combination from ***AASHTO-LRFD Bridge Design Specifications*** **(Section 3.4.1);**
  - This accounts for the sustained load effect that is not yet full characterized for the long term fatigue resistance
- For flexural design typically:
  - $M_{Fat} = M_{sus}$ *(DC & DW)* + M_{LL} *(Fatigue I)*

$$f_{f,f} \leq C_f f_{fd} \quad (2.5.4\text{-}1)$$

where:

$$f_{f,f} = \frac{n_f d(1-k)}{I_{cr}} M_{s,f} \quad (2.5.4\text{-}2)$$

The fatigue rupture reduction factor, C_f, shall be equal to 0.25 unless the GFRP reinforcing bar manufacturer can provide substantiating evidence following ASTM D3479/D3479M asserting that higher values can be safely utilized.

Session 4: Fatigue Design

Fatigue Resistance:

- ***AASHTO-GGS2*** uses 0.25 C_E*f_{fu}

> The fatigue rupture reduction factor, C_f, shall be equal to 0.25 unless the GFRP reinforcing bar manufacturer can provide substantiating evidence following ASTM D3479/D3479M asserting that higher values can be safely utilized.

(previously 0.20 C_E*f_{fu} ***AASHTO-GGS2*** & ***ACI 440.1R-15***)

- ***CSA-S6*** use 0.25 f_{fu}

- May govern designs for continuous structures subject to significant live load, such as:
  - Cast-in-place multi-span flat-slab bridges
  - Decks on SDCL (Simple for Dead Load/Continous for Live Load)

Session 4: Fatigue Design

Fatigue Resistance:

- Parametric study on effect of Elastic Modulus and Resistance Factor under ***AASHTO-GGS2*** for continuous Pile Bent Cap (HRB)

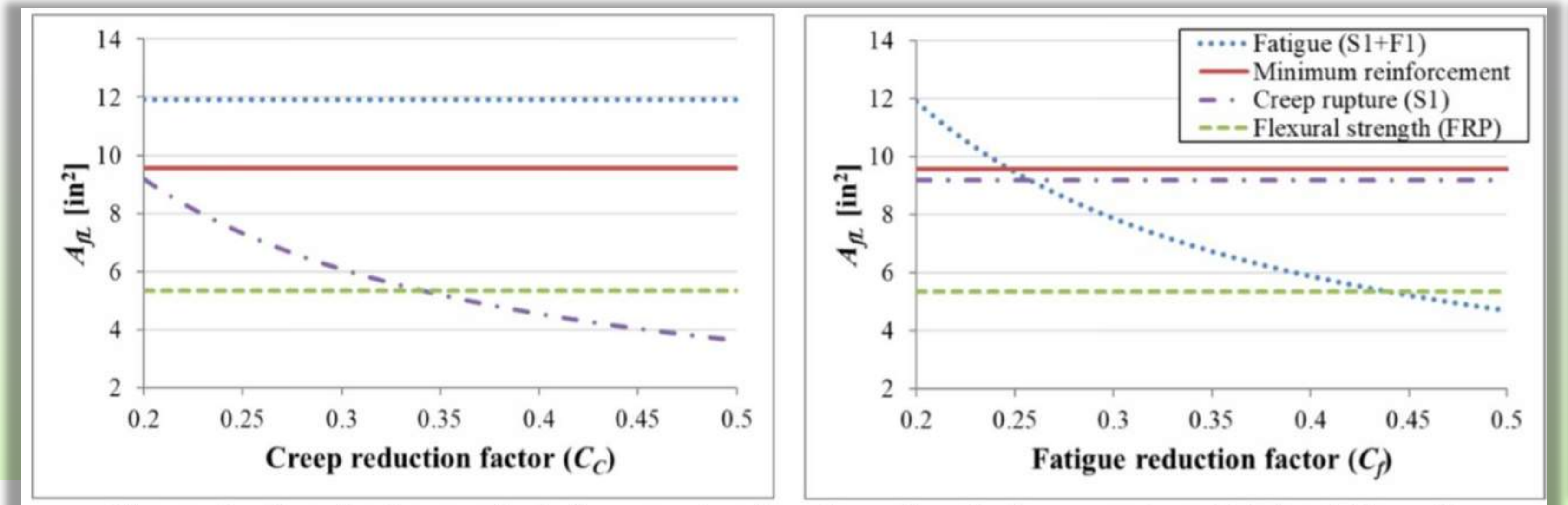
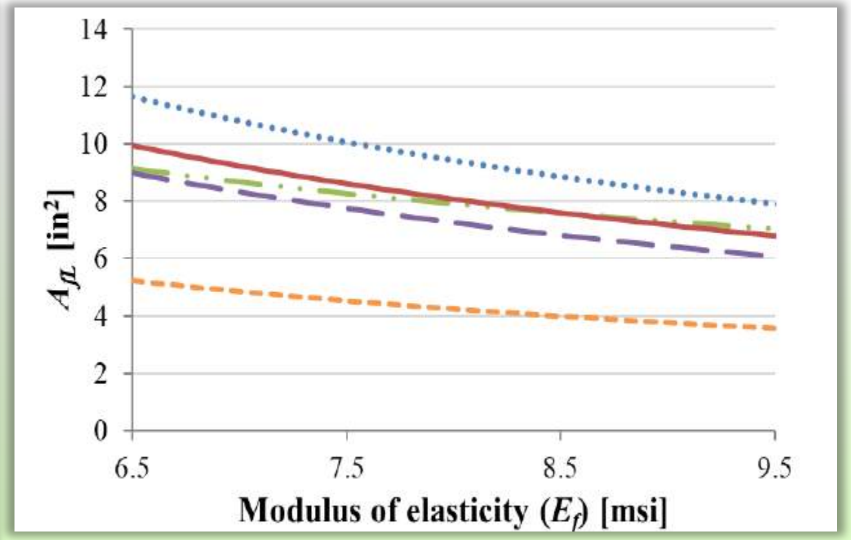


Figure 3 – Required area of reinforcement as function of analysis parameters (1 in² = 645 mm²).



Case-Specific Parametric Analysis as Research-Directing Tool for Analysis and Design of GFRP-RC Structures

Marco Rossini, Eleonora Bruschi, Fabio Matta, Carlo Poggi, Antonio Nanni

Session 4: Minimum Reinforcing

Temperature and Shrinkage:

- ***AASHTO-GGS2*** similar to ***AASHTO-LRFD Bridge Design Specifications (2.9.6)*** but adjusted for the Elastic Modulus (E_f) up to a limit of twice ($\rho_{f,st,\ max}$ *= 2* 0.0018 = 0.0036)* that for carbon-steel ($\rho_{s,st,\ max}$ *= 0.0018*);
- Can govern the design for flexural members with large cross-sectional area, such as:
  - Column Bent Caps
  - Solid Columns
  - Footings

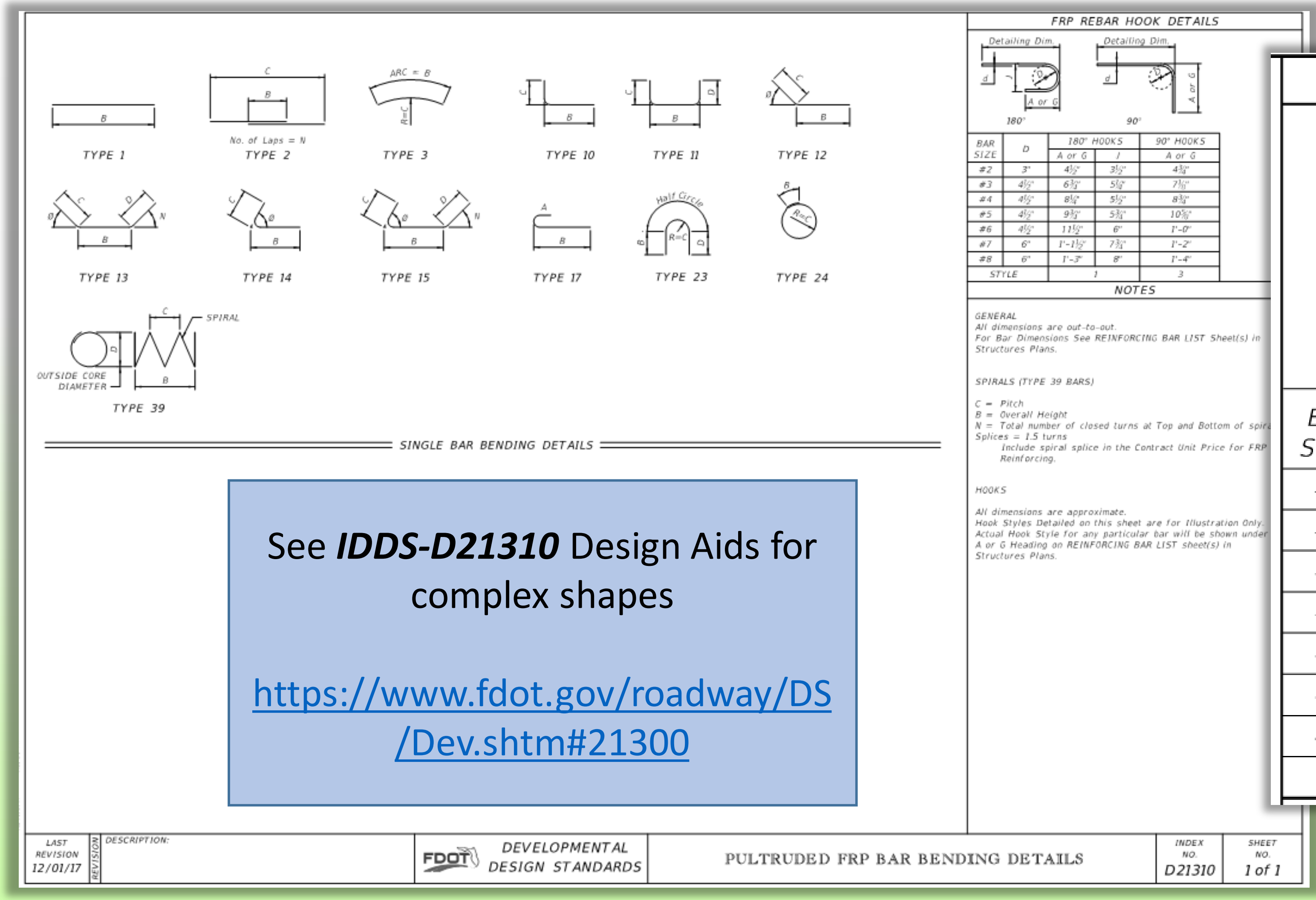
$$\rho_{f,st} = \max\left(\frac{3{,}132}{E_f f_{fd}};\ 0.0014\right) \leq 0.0036 \qquad (2.9.6\text{-}1)$$

$$\rho_{f,st} = 0.0018 \times \frac{60}{f_{fd}}\frac{29{,}000}{E_f} \geq 0.0014 \qquad (C2.9.6\text{-}1)$$

The constant values in Eq. C2.9.6-1 are lumped to obtain Eq. 2.9.6-1.

Session 4: Bar Bends Detailing

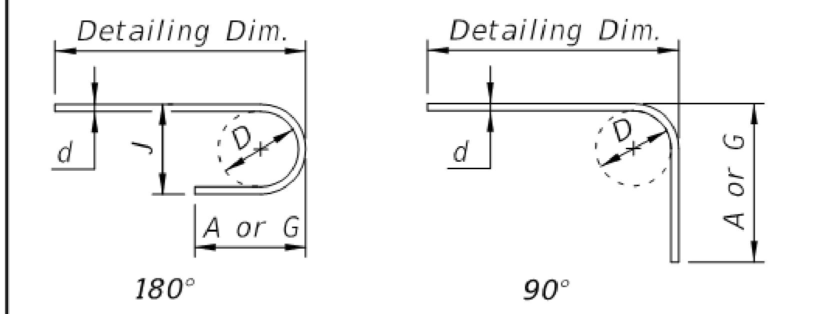
Bar Bend Detailing per ***FDOT Index D21310:***



See ***IDDS-D21310*** Design Aids for complex shapes

https://www.fdot.gov/roadway/DS/Dev.shtm#21300

FRP REBAR HOOK DETAILS



BAR SIZE	D	180° HOOKS		90° HOOKS
		A or G	J	A or G
#2	3"	4½"	3½"	4¾"
#3	4½"	6¾"	5¼"	7⅛"
#4	4½"	8¼"	5½"	8¾"
#5	4½"	9¾"	5¾"	10⅝"
#6	4½"	11½"	6"	1'-0"
#7	6"	1'-1½"	7¾"	1'-2"
#8	6"	1'-3"	8"	1'-4"
STYLE		1		3

Session 4: Bar Splice Detailing

Tension Lap Splicing per AASHTO-GGS2 & IDDS-D21310:

Tension Development Length Equation:

$$\ell_d \geq \max\left(\frac{31.6\,\alpha \frac{f_{fr}}{\sqrt{f'_c}} - 340}{13.6 + \frac{C}{d_b}} d_b;\ 20 d_b \right) \qquad (2.9.7.4.1\text{-}1)$$

2.9.7.6—Splices of GFRP Reinforcing Bar

Permissible locations, types, and dimensions of splices, including staggers, for GFRP reinforcing bars shall be shown in the contract documents.

The length of lap for tension GFRP reinforcing bars shall not be less than 12 in. or $1.3\ell_d$, whichever is greater.

The length of lap for compression GFRP reinforcing bars shall not be less than 12 in. or $1.3\,\ell_d$, where ℓ_d is computed using Eq. 2.9.7.4.1-1 where $f_{fr} = 0.25\,f_{fu}$.

Bars spliced by noncontact lap splices in flexural members shall not be spaced center-to-center farther apart transversely than the lesser of one-fifth the required lap splice length and 6 in.

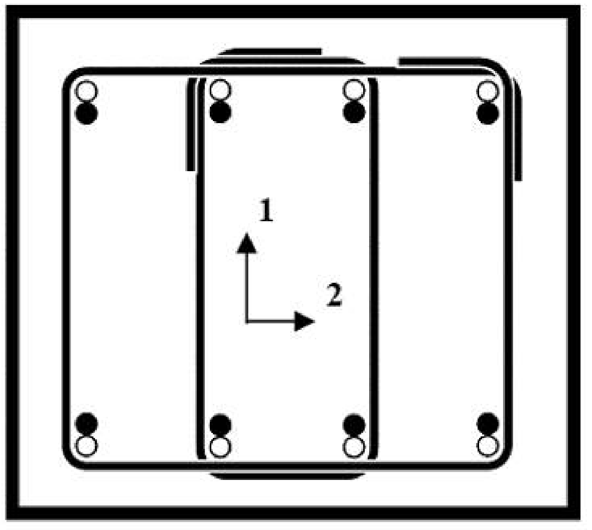
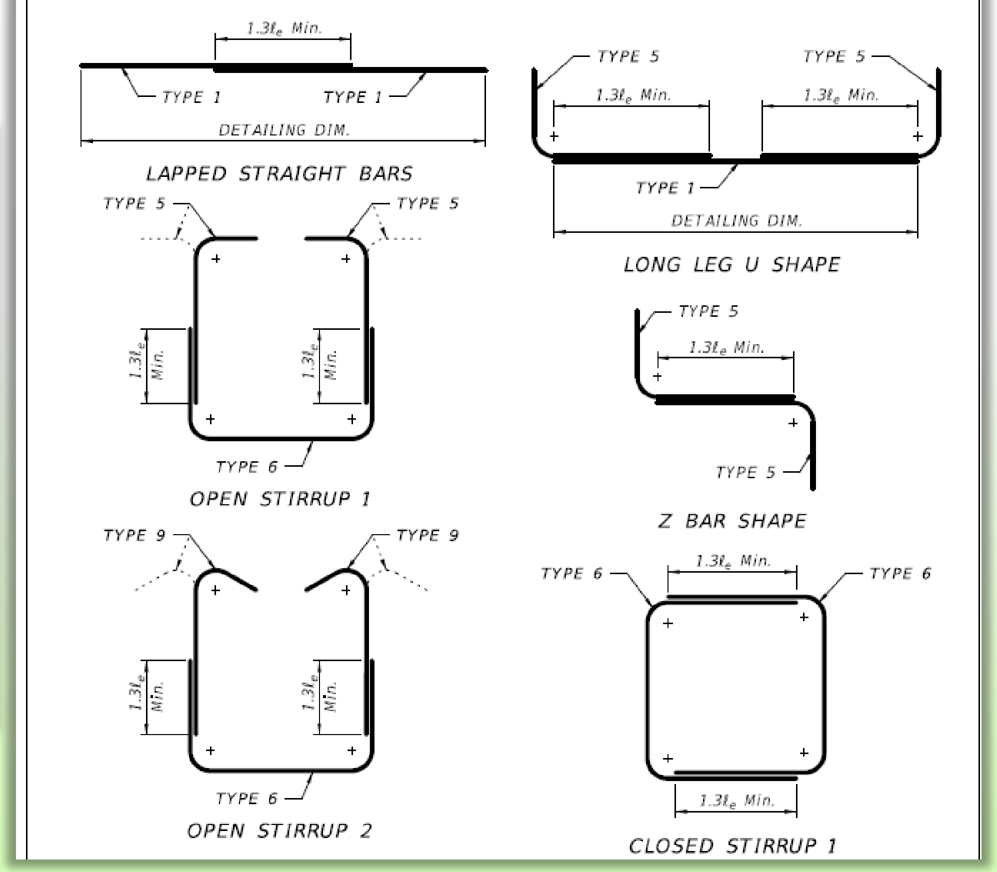


Figure C4.5.8-1—Lap Splice Requirements for Columns

Design Aids



Questions

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