NEW DEVELOPMENT IN PRECAST PRESTRESSED CONCRETE BRIDGES IN WASHINGTON STATE

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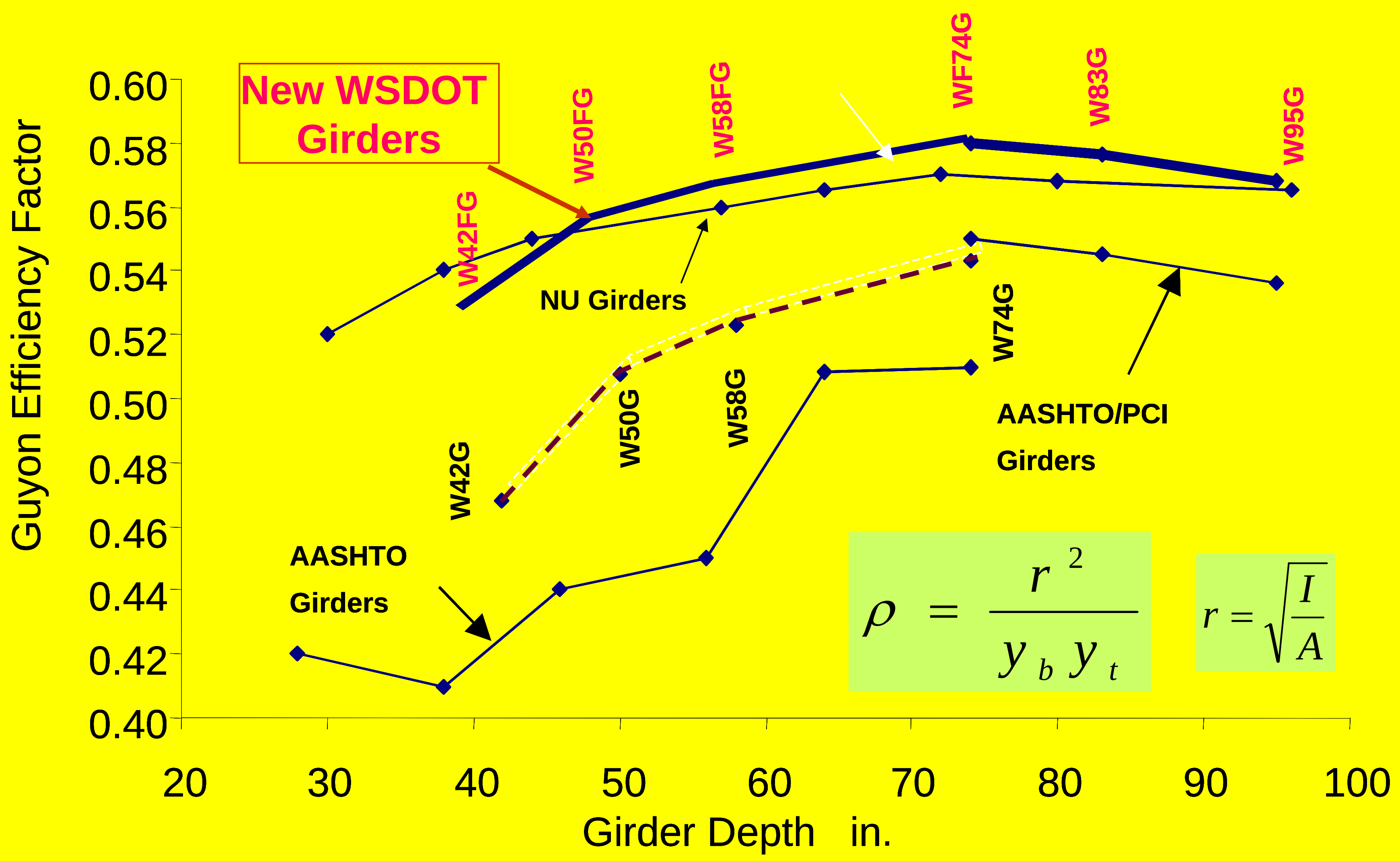
PRESENTATION OUTLINE

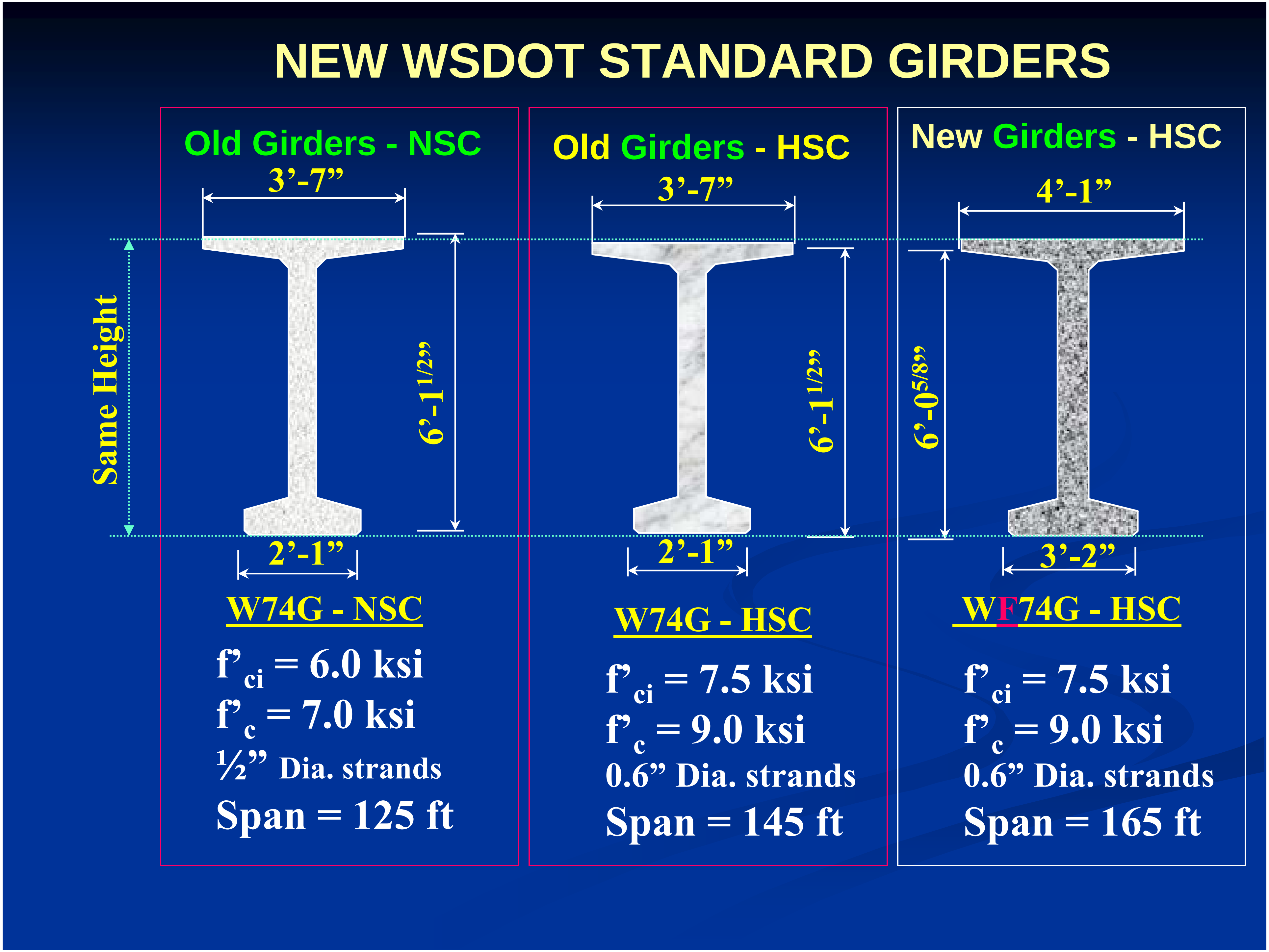
- ✓ Concrete Bridge Superstructure
- ✓ AASHTO LRFD Specifications
- ✓ WSDOT Design Requirements
- ✓ Precast Girders
- ✓ Cncrete Deck Slab
- ✓ Precast Substructure
- ✓ Modifications to Bridge Construction

PRECAST SUPERSTRUCTURE: WSDOT WIDE FLANGE I-GIRDERS

Span Capability, ft	
WF42G	110
WF50G	125
WF58G	140
WF74G	165
W83G	180
W95G	200

EFFICIENCY OF PRESTRESSED GIRDERS

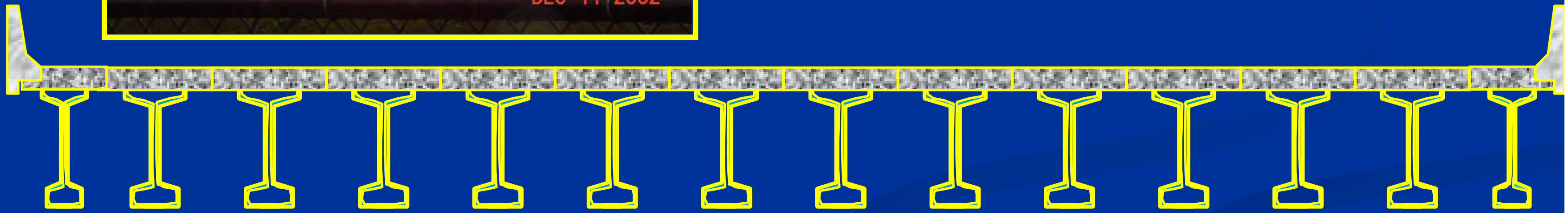



NEW WSDOT STANDARD GIRDERS
Same Height
Old Girders - NSC
3’-7”
6’-1 1/2”
2’-1”
W74G - NSC
f’ci = 6.0 ksi
f’c = 7.0 ksi
½” Dia. strands
Span = 125 ft
Old Girders - HSC
3’-7”
6’-1 1/2”
2’-1”
W74G - HSC
f’ci = 7.5 ksi
f’c = 9.0 ksi
0.6” Dia. strands
Span = 145 ft
New Girders - HSC
4’-1”
6’-0 5/8”
3’-2”
WF74G - HSC
f’ci = 7.5 ksi
f’c = 9.0 ksi
0.6” Dia. strands
Span = 165 ft

DAMAGED PRESTRESSED GIRDER BRIDGE

Superstructure Replacement, Span = 145 ft

Span 8 ~
48 feet Above Tracks

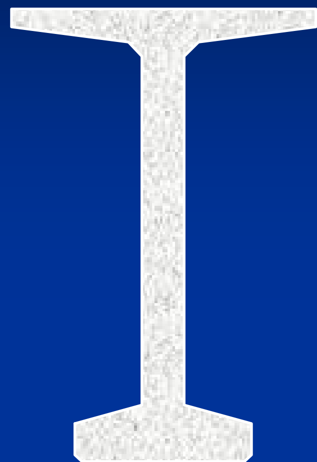


Existing: 15 – W74G Girder

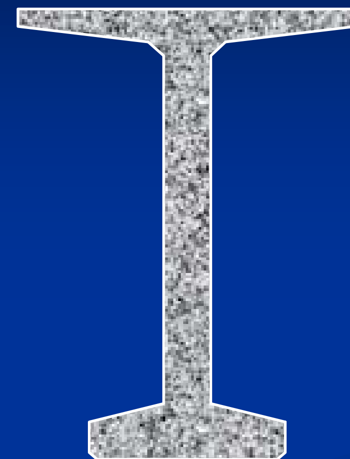
Replacement: 8 – WF74G Girder

Comparison: New Girder-HSC vs. Old Design

Superstructure Replacement, Span = 145 ft



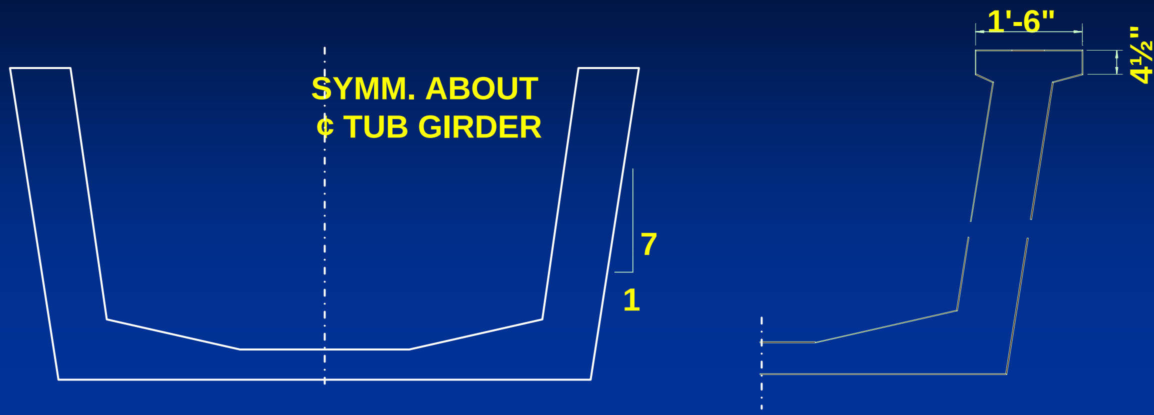
W74G - NSC



WF74G - HSC

No	Length ft	ft²	PS Steel in2	Volume cy	Conc kips	Cement kips	GHGE kips
15	145	4.96	91.8	399.39	63.90	15.98	15.98
7	145	6.22	78.9	233.76	37.40	9.35	9.35
			14.0% materials	41.4% materials	41.4% Shipping	41.4% Material	41.4% Environ.

PRECAST SUPERSTRUCTURE: PRETENSIONED U-GIRDERS

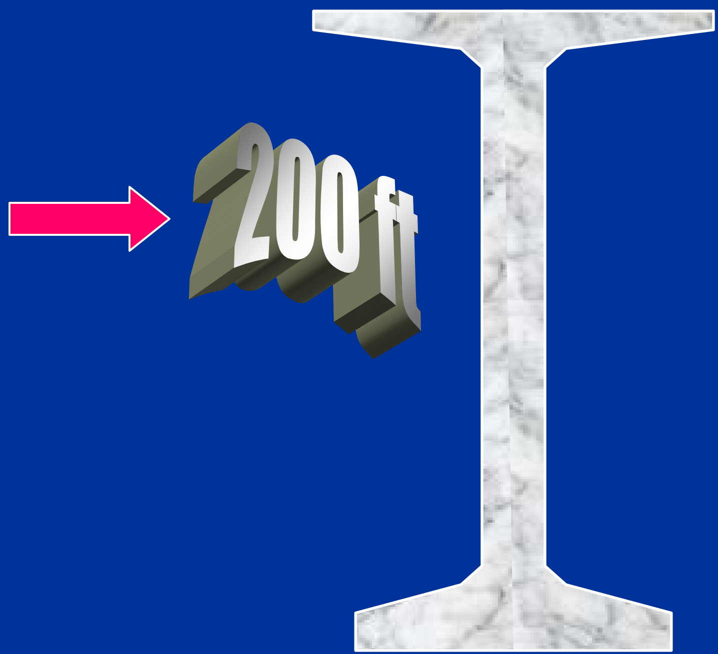


TRAPEZOIDAL TUB
SECTION

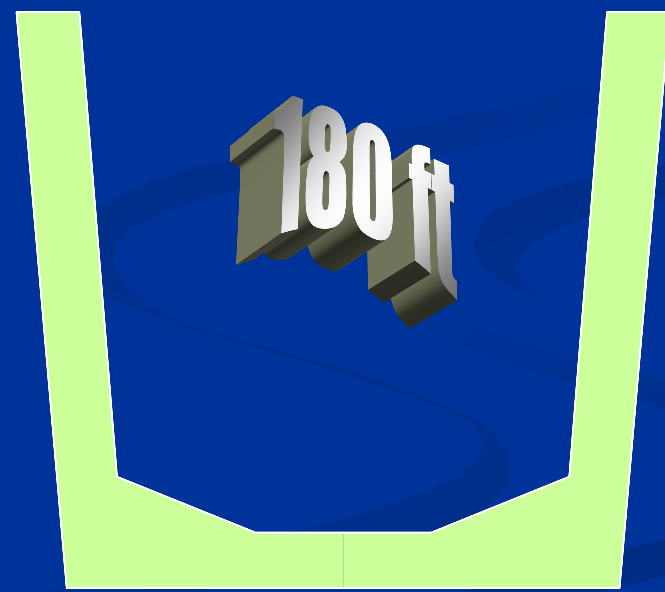
Span Capability, ft	
U54G4	130
U66G4	155
U78G4	170
UF60G4	150
UF72G4	165
UF84G4	185

LONG SPAN PRESTRESSED GIRDERS

- **New Casting Bed**
- **Up To 100 – 0.6” Dia Strands**
- **New Trucking System > 200 Kips (265 Kips)**



W95G



TRAPEZOIDAL TUB SECTION

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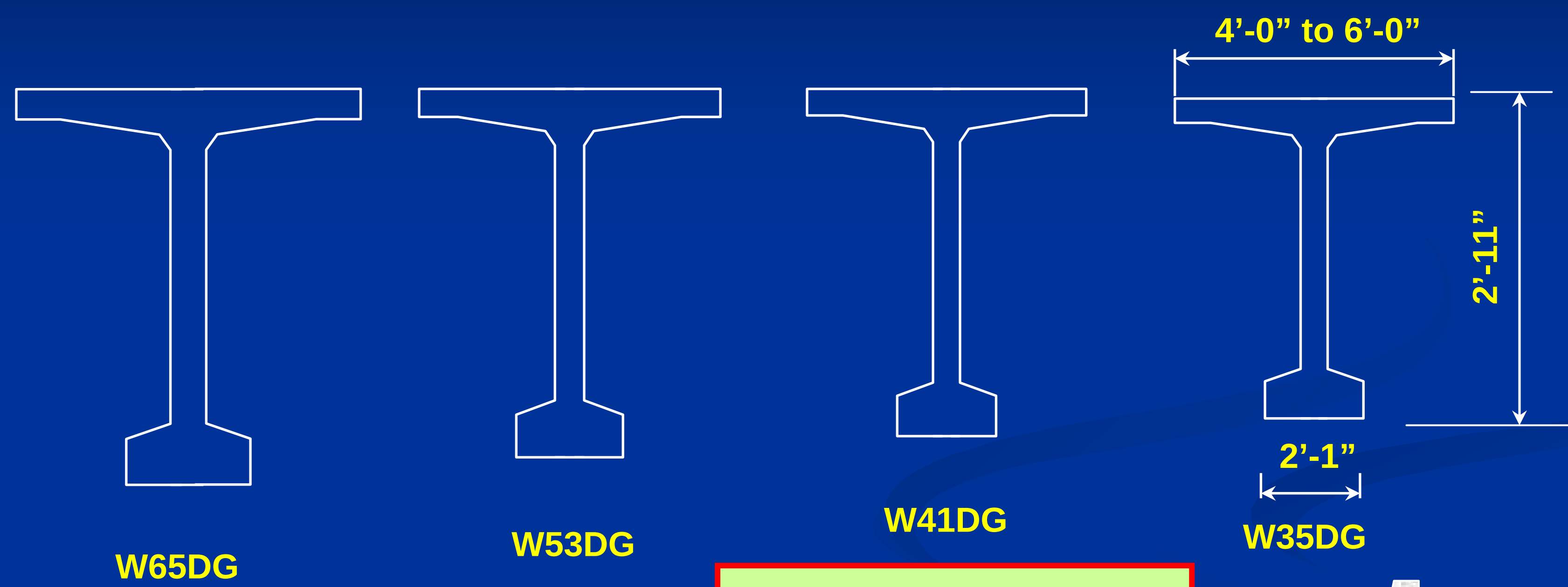
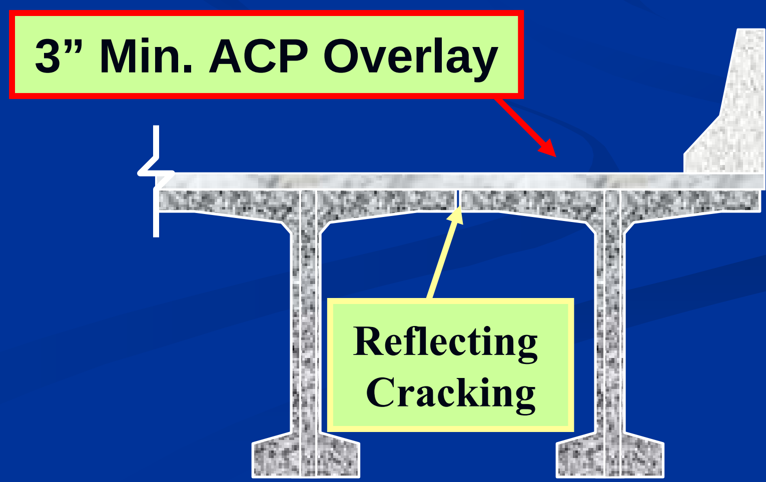
Standard Deck Bulb Tee Girders

Non-Composite Section ~ ADT < 30,000



Span Capability, ft	
W35DG	90
W41DG	115
W53DG	130
W65DG	145



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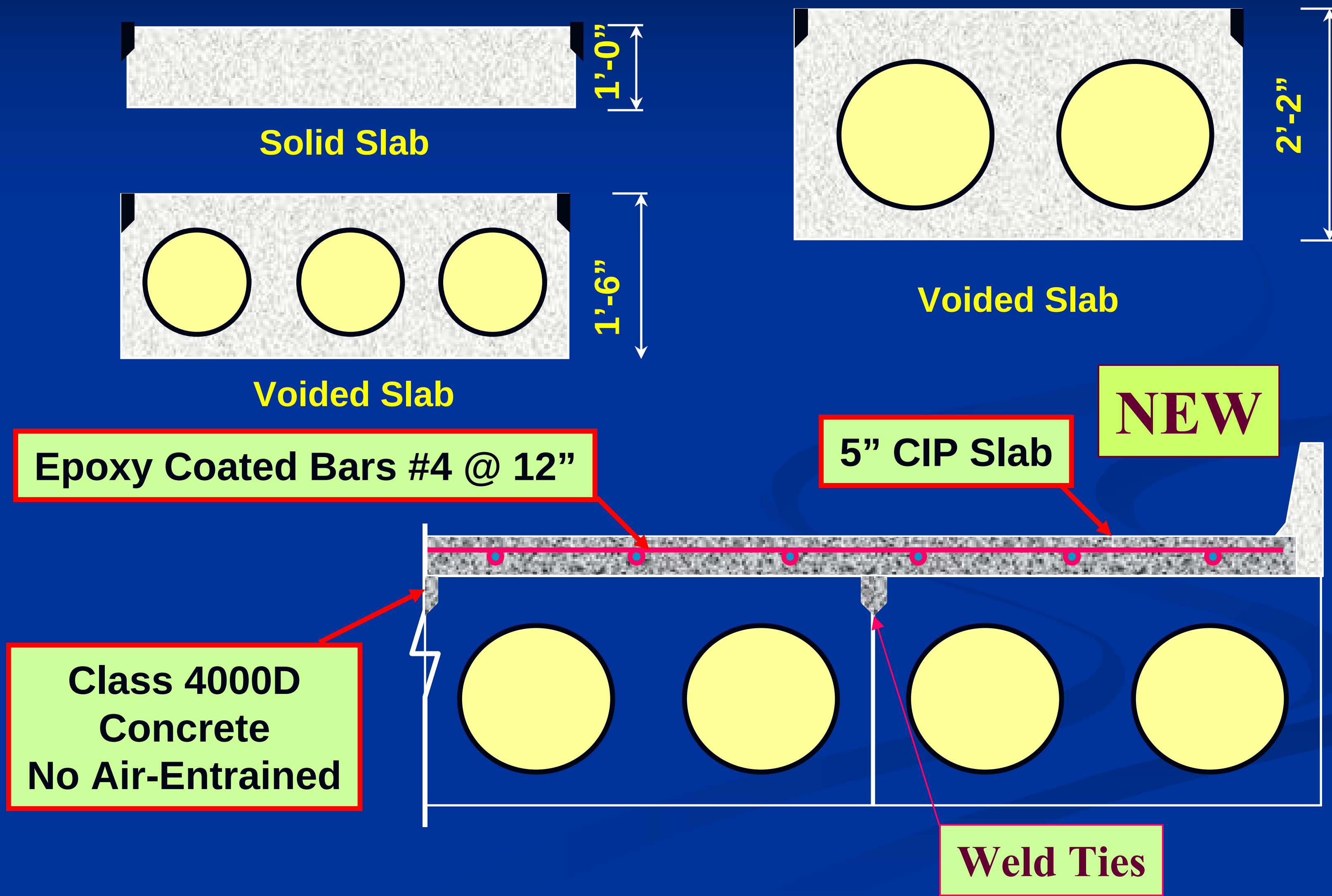
Composite Section ~ 5” Min. CIP Slab



DESIGN POLICY FOR PS GIRDER BRIDGES

AASHTO LRFD $\Sigma \eta_i \gamma_i Q_i < \phi R_n = R_r$

- **Design For Zero Tension At Service**
- **Design For Simple Span For DL And LL**

  (Provide Continuity Reinforcement At Intermediate Piers For Negative LL & SIDL)
- **Design For Shipping And Handling**
- **Design For Seismic Events**
- **Design For Continuity – Joint Less Bridges**

Material Properties – Current Practice

Concrete:

- Precast Girder – HPC/HSC
  - Transfer 7.5 ksi
  - Final at 28 days 9.0 ksi
- Slab – Class 4000D 4.0 ksi
- CIP PT girders Class 4000 4.0 ksi
- NO SCC (Self Consolidating Concrete)
  For prestressed girder applications

Material Properties

Reinforcing steel

- **A706 Steel for all bridge applications**

  (A615 Steel Grade 60 for some applications)

- **WWF for some applications - fy = 60 ksi**

- **No MMFX A1035 Steel - fy > 100 ksi**

  (One on one replacement for Deck Slab)

Creep of Concrete - Current Practice

The creep coefficient may be taken as follows:

$$\psi(t,t_i) = 1.9 k_{vs} k_{hc} k_f k_{td} t_i^{-0.118}$$

in which:

$$k_{vs} = 1.45 - 0.13(V/S) \geq 1.0$$

$$k_{hc} = 1.56 - 0.008H$$

$$k_f = \left(\frac{5}{1 + f_{ci}}\right)$$

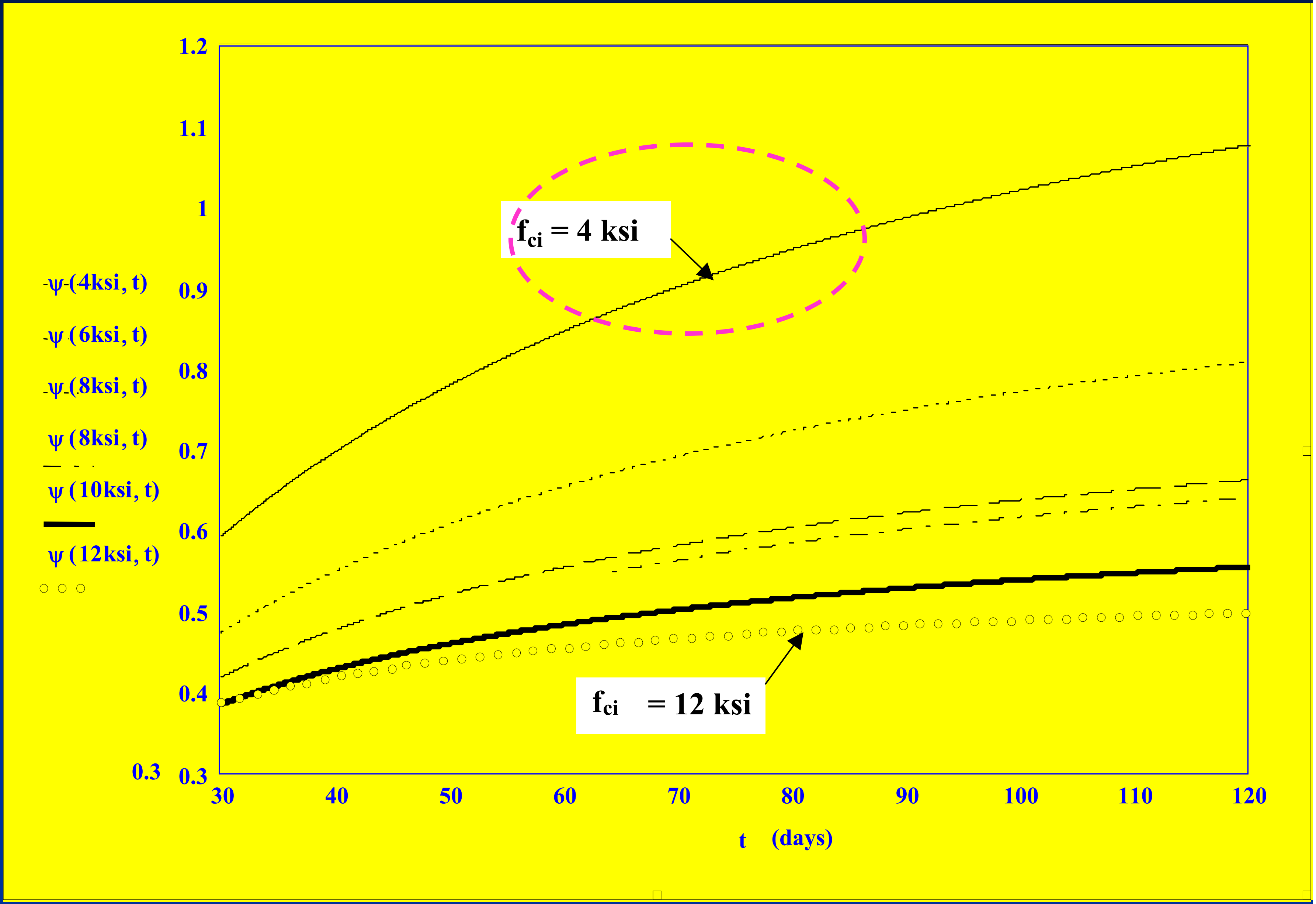
$$k_{td} = \left(\frac{t}{61 - 4f_{ci} + t}\right)$$

Used for all creep calculations

where:

- H = relative humidity (%), equal to 75% for standard conditions
- k_{vs} = factor for the effect of the volume-to-surface ratio of the component
- k_{hc} = humidity factor for creep
- k_f = factor for the effect of concrete strength
- k_{td} = time development factor

Creep Coefficients



BRIDGE DESIGN SPECIFICATIONS

- AASHTO LRFD
- Bridge Design Manual, BDM

$$\Sigma \eta_i \gamma_i Q_i < \phi R_n = R_r$$

Current Seismic Design Criteria:

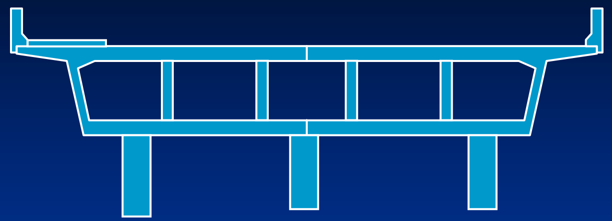
- Force-based" Seismic provisions

The LL factor for Extreme Event-I Limit State: $\gamma_{EQ} = 0.5$

The Seismic LL factor apply to LL forces (LL mass is ignored in dynamic analysis)

LL Distribution Factor

AASHTO STD Specifications



$$DF = \frac{Overall\_Slab\_width}{14}$$

AASHTO LRFD Table 4.6.2.2.2b-1

$$DF = DF_i \times N_b$$

Two or more lanes:

$$DF_i = \left(\frac{13}{Nc}\right)^{0.3}\left(\frac{S}{5.8}\right)\left(\frac{1}{L}\right)^{0.25}$$

Single lane:

$$D.F. = \left(1.75 + \frac{S}{3.6}\right)\left(\frac{1}{N_c}\right)^{0.45}\left(\frac{1}{L}\right)^{0.35}$$

Lumped Distribution Factor

$$DF = 2 \times DF_e + (N_b - 2)DF_i$$

Live load distribution factor for multicell box girder:

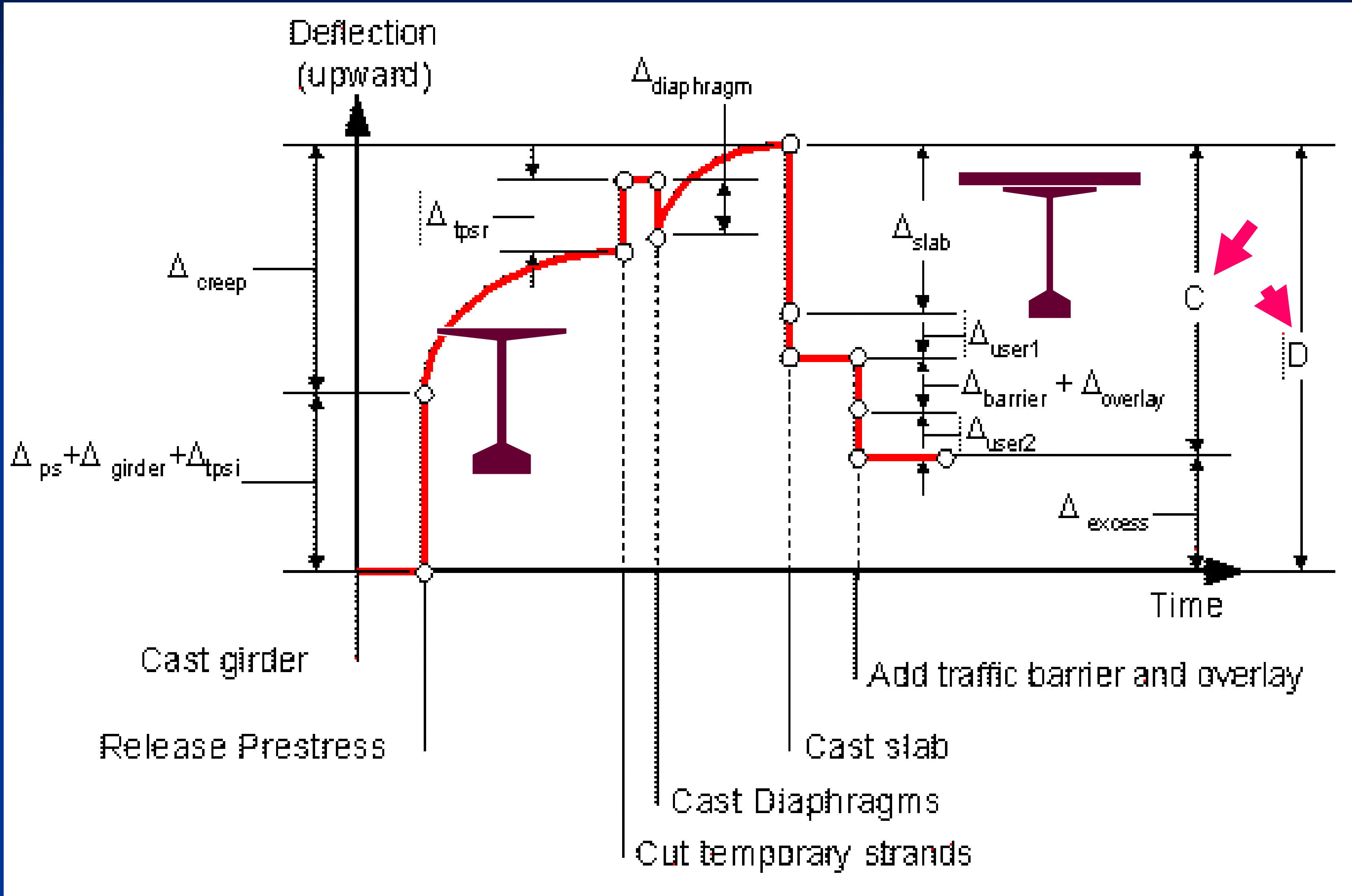
$$DF = N_b \, x \, DF_i$$

Where:

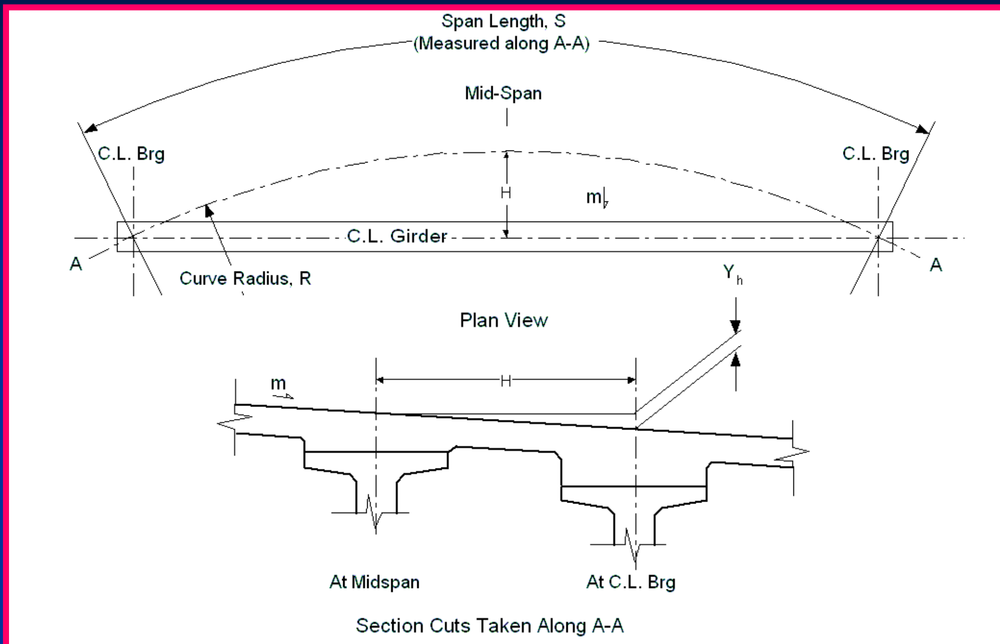
DF_i = Live load distribution factor for interior web

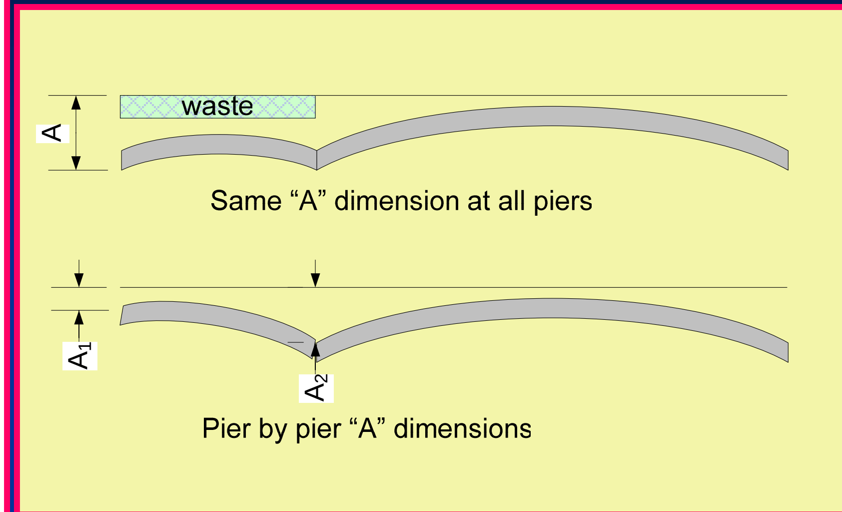
N_b = Number of webs

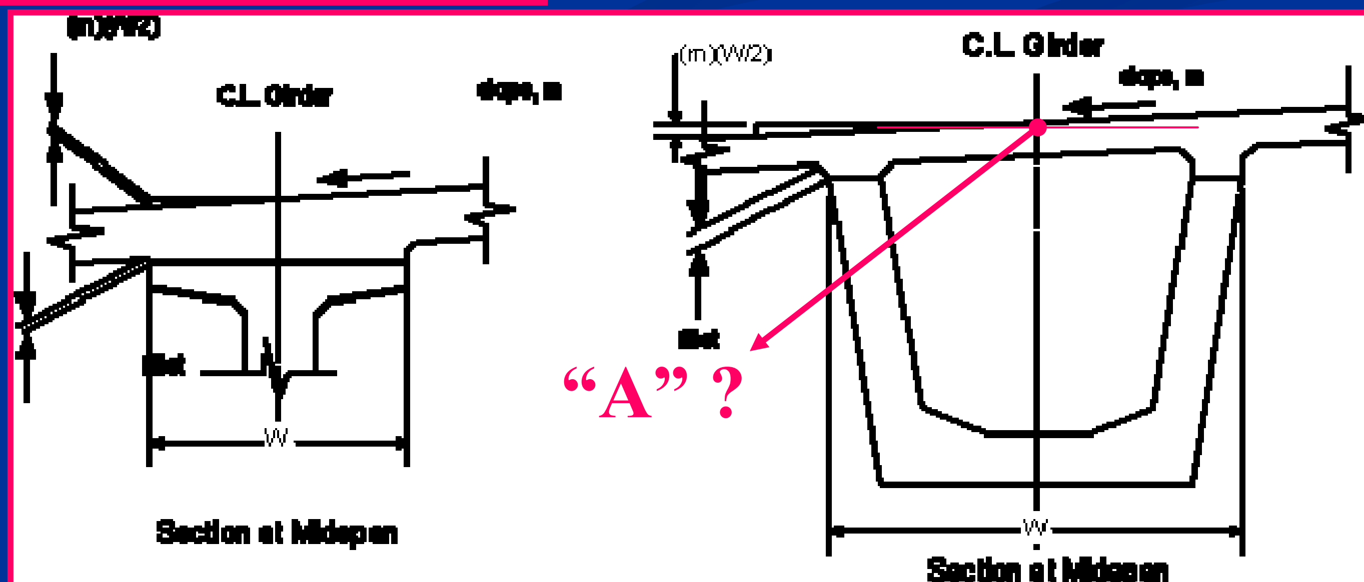
CAMBER OF PRESTRESSED GIRDERS



GENERALIZED “A” DIMENSION







ACCELERATED BRIDGE CONSTRUCTION

In The Contract Plans:

Provide Camber Information At:

➡ 40 Days And 120 Days

"A" Dimension At 120 Days (Conservative)

	Rapid Construction	Normal Construction
Release of temp. Strands	30 days	90 days
Casting Diaphragms:	30 days	90 days
Casting deck slab "D":	40 days	120 days

PRESTRESS LOSSES

- Instantaneous Losses
- Time-Dependent Losses

Approximate Method:

$$\Delta f_p = 33.0\left[1.0 - 0.15\frac{f'_c - 6}{6}\right] + 6\ \text{PPR} - 6.0\ \text{(Low Relax)}$$

$$\gamma_h = 1.7 - 0.01H$$

$$\gamma_{st} = \frac{5}{(1 + f'_{ci})}$$

$$\Delta f_{pLT} = 10.0\frac{f_{pi}A_{ps}}{A_g}\gamma_h\gamma_{st} + 12.0\gamma_h\gamma_{st} + \Delta f_{pR}$$

Use Refined Method for Prestress Losses

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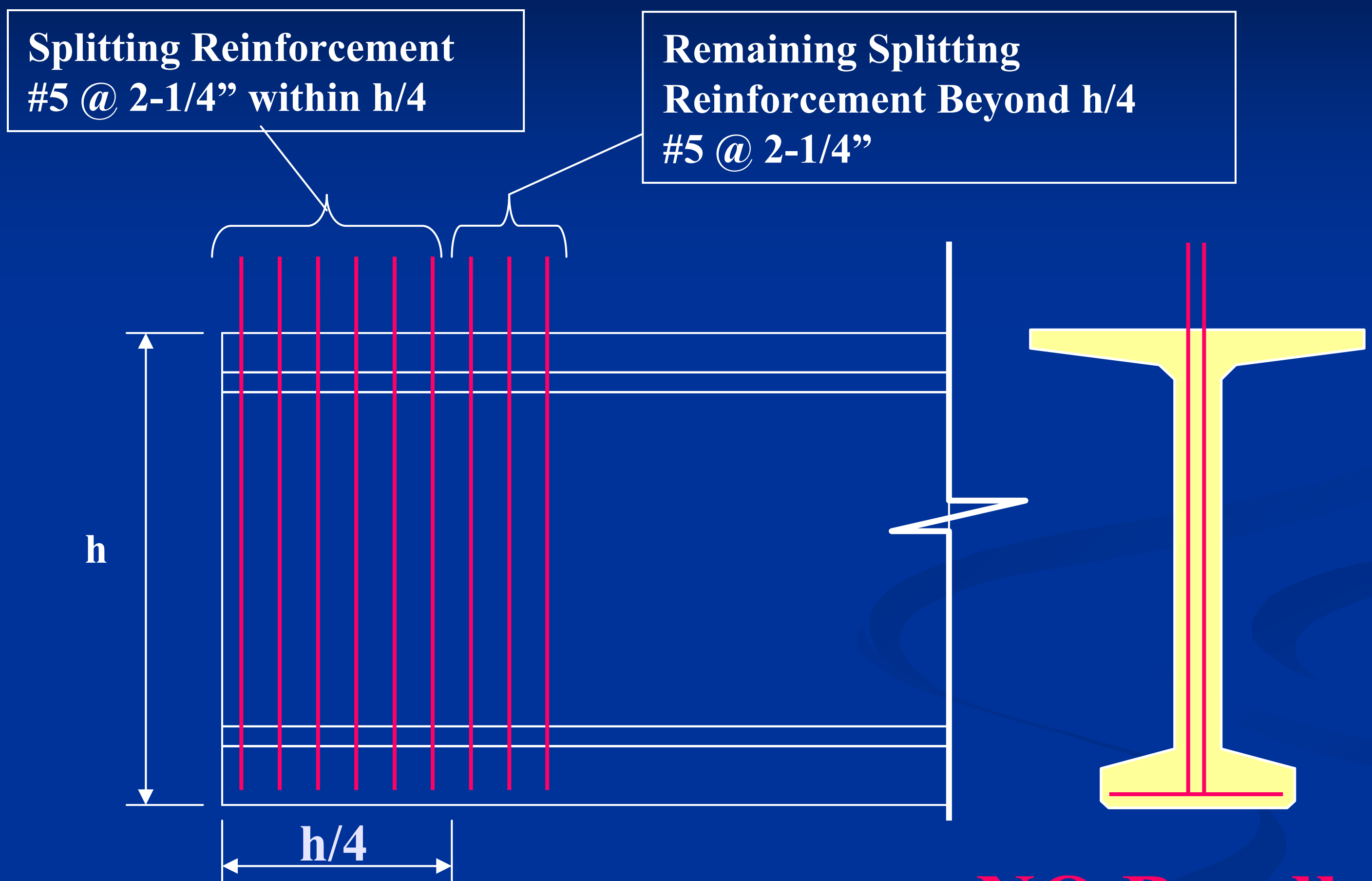
Friction Coefficient for PT Tendons in Semi-Rigid Galvanized Metal Duct

Tendon length	Metal Ducts -Galvanized		Plastic Ducts- HDPE	
	Friction μ	wobble k	μ	k
500 ft or Less	0.15	0.0002	0.15	0.001
Over 500 to 750 ft	0.20			
Over 750 to 1000 ft	0.25			

For tendon lengths greater than 1000 feet, investigation is warranted on current field data of similar length bridges for appropriate values of μ

NEW: WSDOT is Gradually Requiring HDPE Plastic Ducts for all PT Applications (Transverse & Longitudinal)(Pilot Projects)

SPLITTING REINFORCEMENT I-GIRDERS

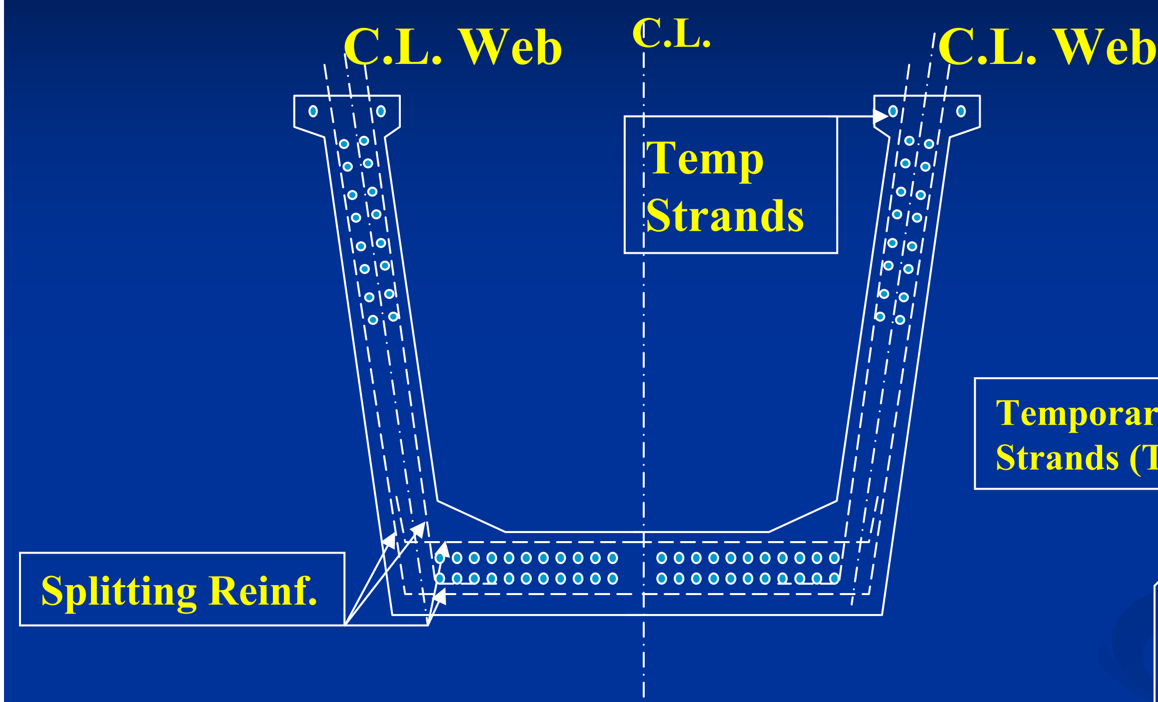


<u>Prestressed Girder</u>

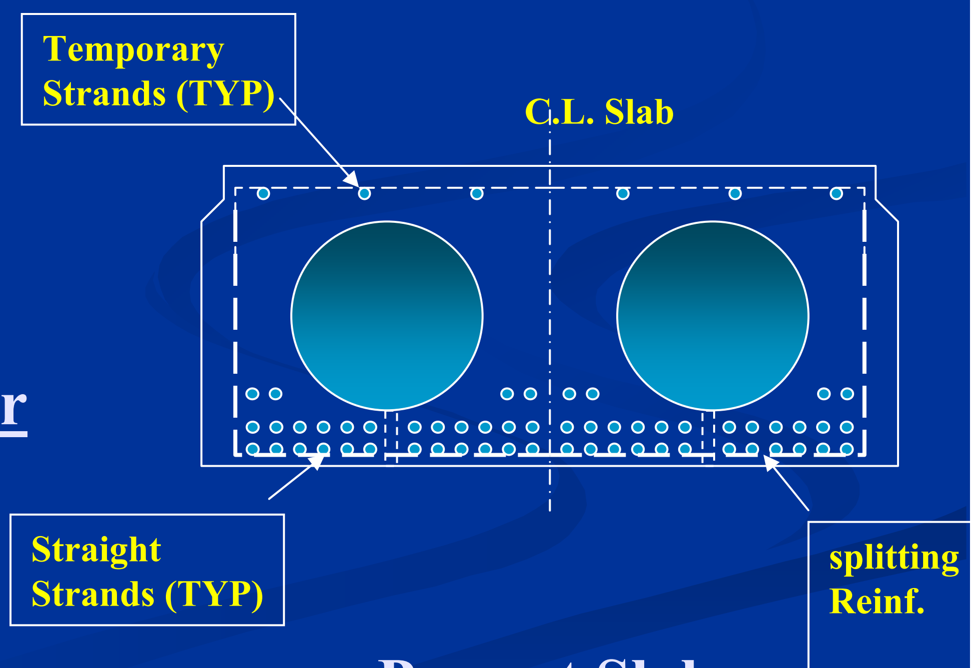
Section Near End

- NO Bundled bars
- NO #6 Bars

SPLITTING REINFORCEMENT



Trapezoidal Tub Girder
Strand Pattern

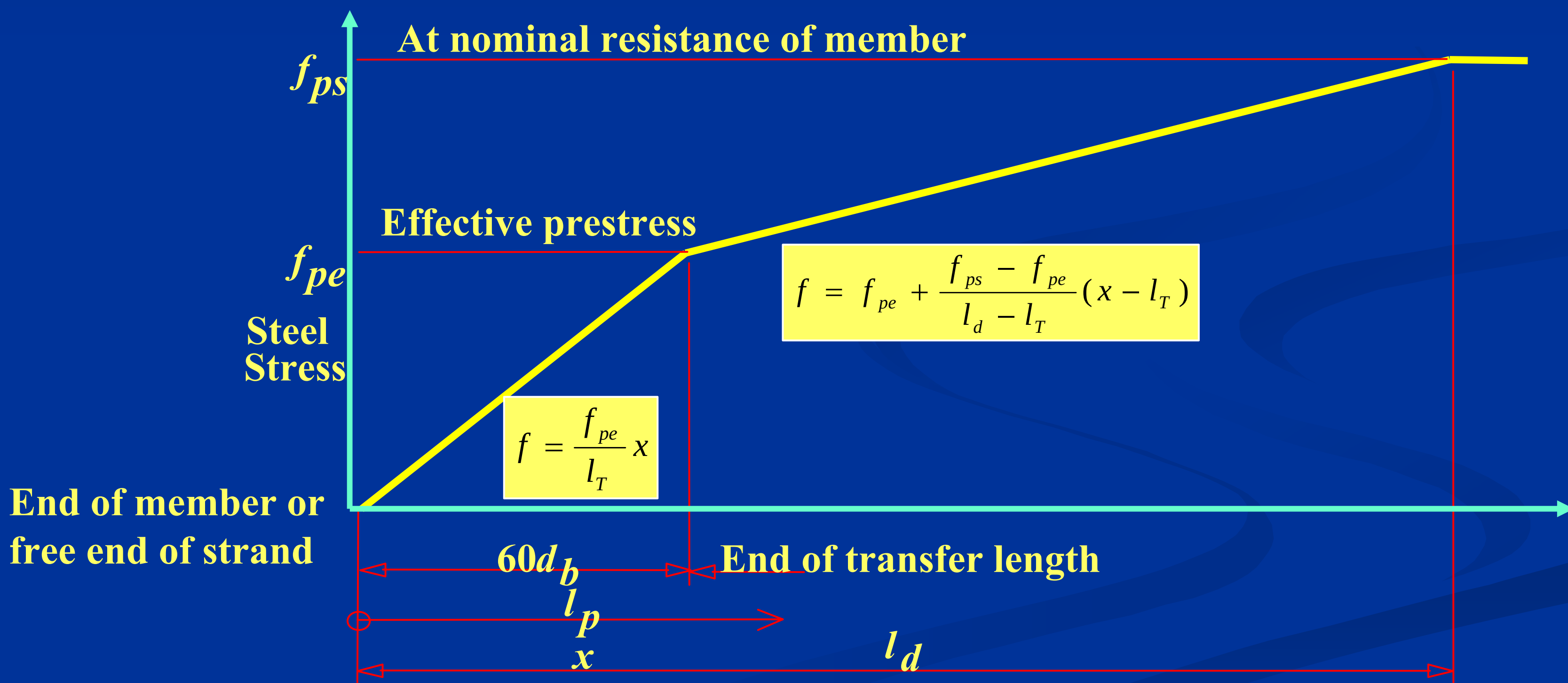


Precast Slab
Strand Pattern

TRANSFER AND DEVELOPMENT LENGTH OF PRESTRESSING STRANDS

Transfer Length: $L_T = 60 \times d_b$

Development Length: $l_d \geq K\left(f_{ps} - \frac{2}{3} f_{pe}\right) d_b$



Idealized relationship between steel stress and distance from the free end of strand

TRANSFER AND DEVELOPMENT LENGTH OF EPOXY COATED STRANDS

Shorter Transfer Length Results is Rapid Transfer of PS Force into the Girder

FLEXURAL STRENGTH

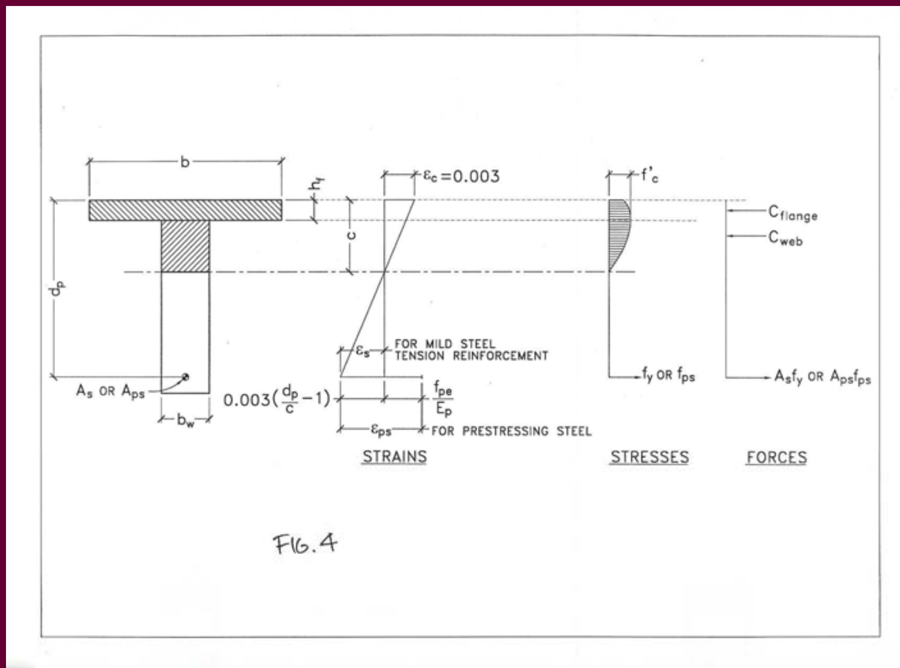
Non-Linear Strain Compatibility

Estimate stress in each steel layer

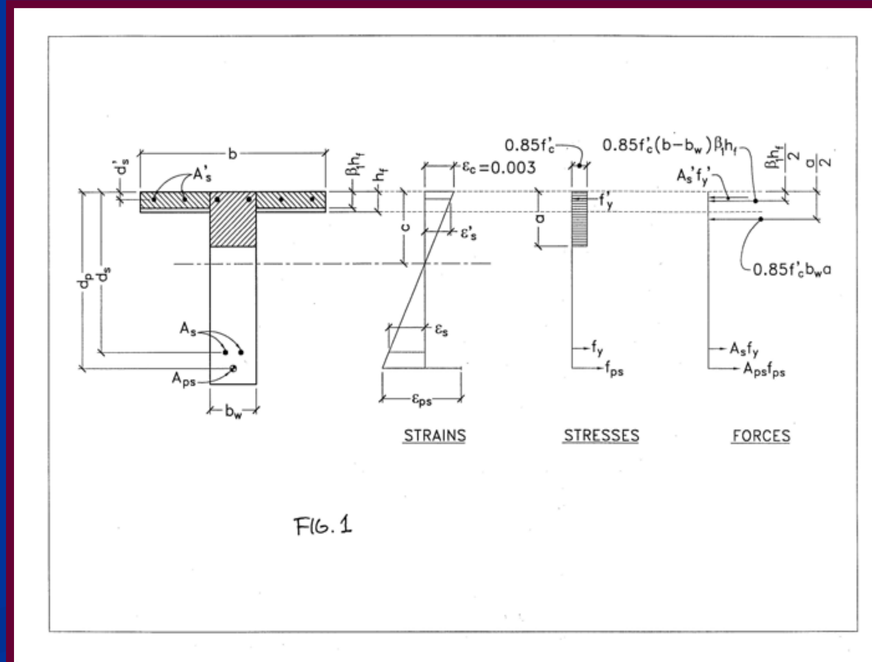
$$\sigma_{si} = \varepsilon_{si}\ [887+27613/\{1+(112.4\varepsilon_{si})7.36\}^{1/736}] <= 270\ \text{ksi}$$

Calculate the nominal flexural capacity

$$\phi M_n = \Sigma\, A_{si}\, \sigma_{si}\, d_i + \Sigma\, F_{cj}\, d_j$$

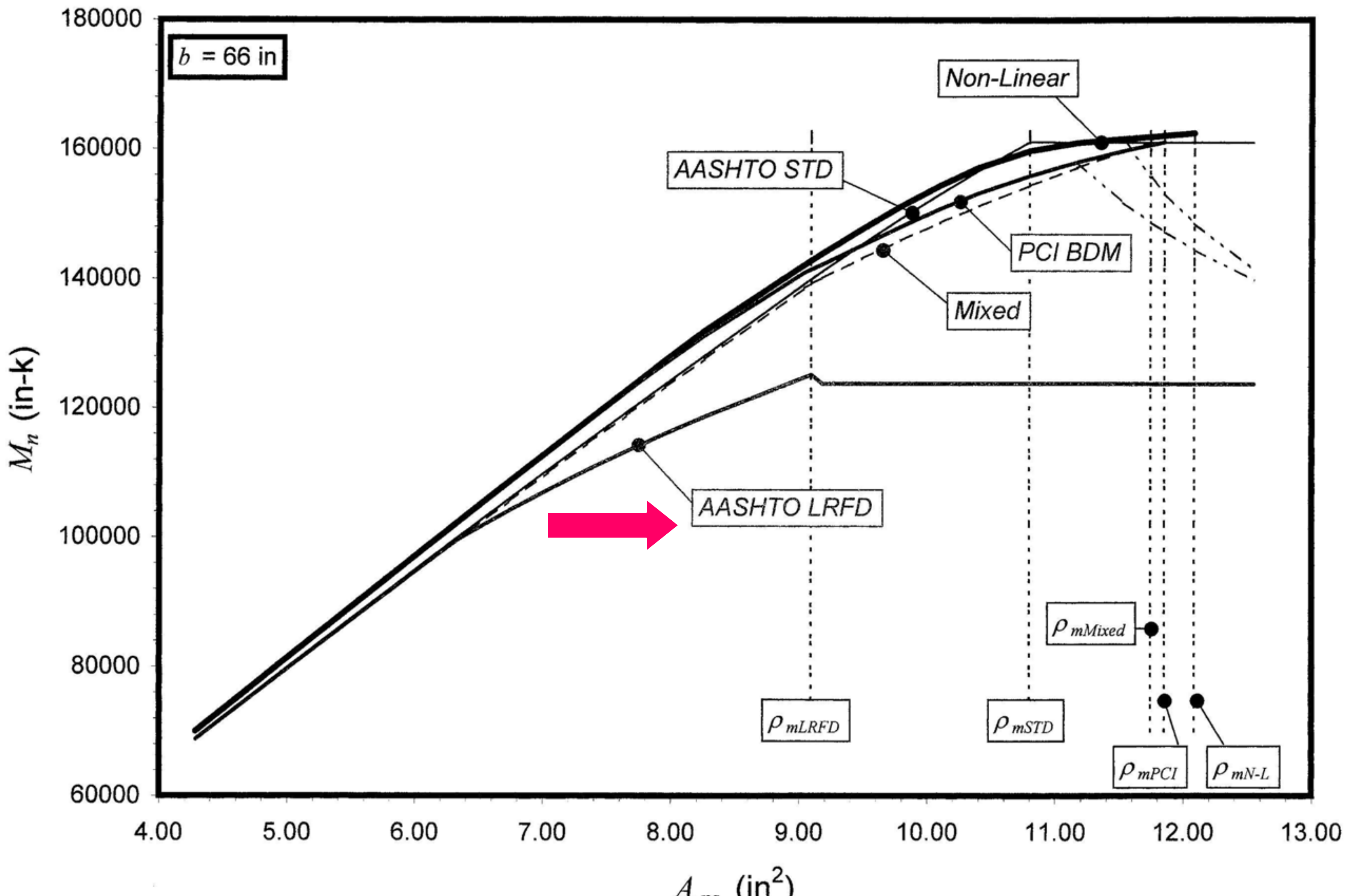


Non-Linear Strain Compatibility



Linear Strain Compatibility

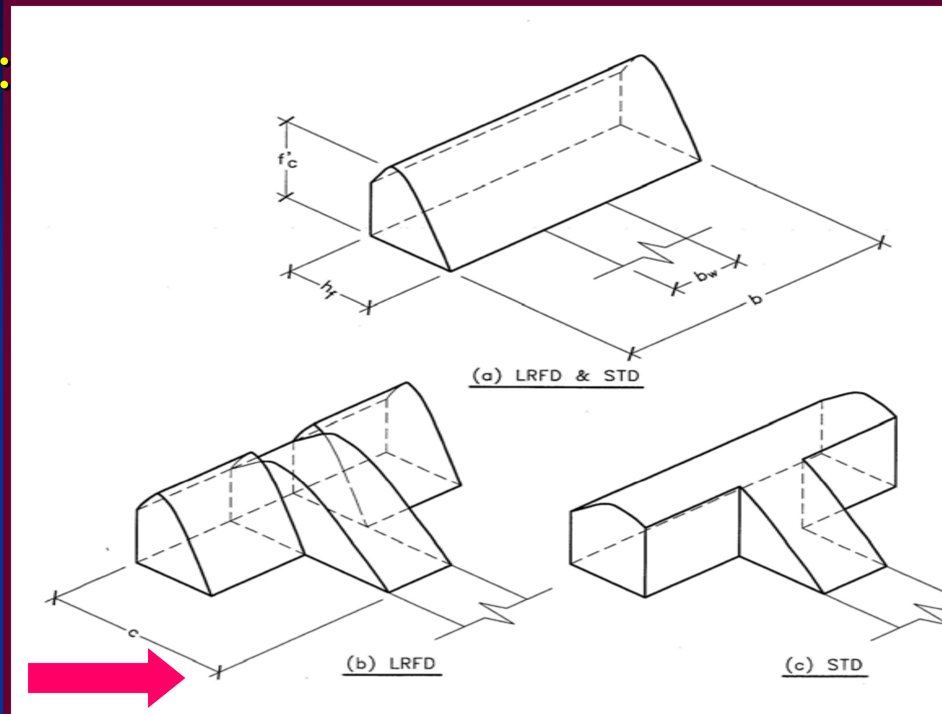
FLEXURAL STRENGTH OF T-BEAMS



NOMINAL FLEXURAL RESISTANCE - STRENGTH LIMIT STATE

For rectangular section behavior:

$$c = \frac{A_{ps} f_{pu} + A_s f_y - A'_s f'_y - 0.85 \cancel{\beta_1} f'_c (b - b_w) h_f}{0.85 f'_c \beta_1 b_w + k A_{ps} \dfrac{f_{pu}}{d_p}}$$



For T-Beam behavior:

$$c = \frac{A_{ps} f_{ps} + A_s f_y - A'_s f'_y - 0.85 \cancel{\beta_1} f'_c (b - b_w) h_f}{0.85 f'_c \beta_1 b_w}$$

Nominal Flexural Resistance:

$$M_n = A_{ps} f_{ps}\left(d_p - \frac{a}{2}\right) + A_s f_y \left(d_s - \frac{a}{2}\right) - A'_s f'_y \left(d'_s - \frac{a}{2}\right) + 0.85 f'_c (b - b_w) \cancel{\beta_1} h_f \left(\frac{a}{2} - \frac{h_f}{2}\right)$$

Stress in Prestressing Steel:

$$k = 2\left(1.04 - \frac{f_{py}}{f_{pu}}\right) \qquad f_{ps} = f_{pu}\left(1 - k\frac{c}{d_p}\right)$$

Maximum Flexural Reinforcement

The maximum amount of prestressed and non-prestressed reinforcement shall be such that:

Otherwise:

$$\frac{c}{d_e} \leq 0.42$$

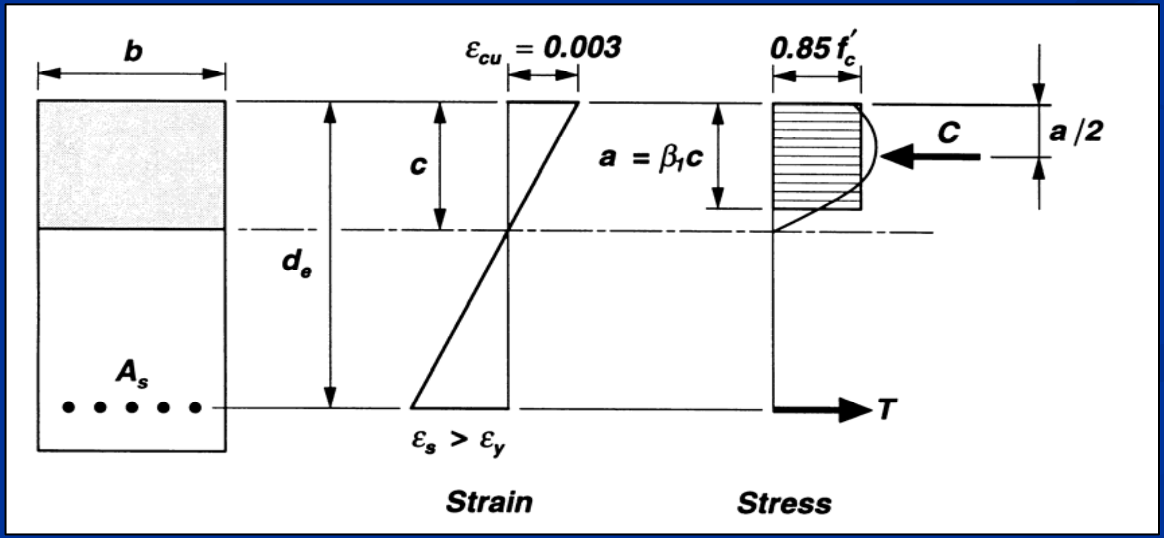
$$d_e = \frac{A_{ps} f_{ps} d_p + A_s f_y d_s}{A_{ps} f_{ps} + A_s f_y}$$

Rectangular

$$M_n = (0.36\beta_1 - 0.08\beta_1^2) f`_c b d_e^2 =$$

T-Beam

$$M_n = (0.36\beta_1 - 0.08\beta_1^2) f`_c b d_e^2 + 0.85 f`_c (b - b_w) h_f (d_e - 0.5 h_f) =$$



$$\frac{c}{d_e} = 0.42$$

$$\frac{0.003}{0.42 d_e} = \frac{\varepsilon_s}{(1 - 0.42) d_e}$$

$$\varepsilon_s = 0.003 \left(\frac{1 - 0.42}{0.42} \right) = 0.00414 \approx 2\varepsilon_y$$

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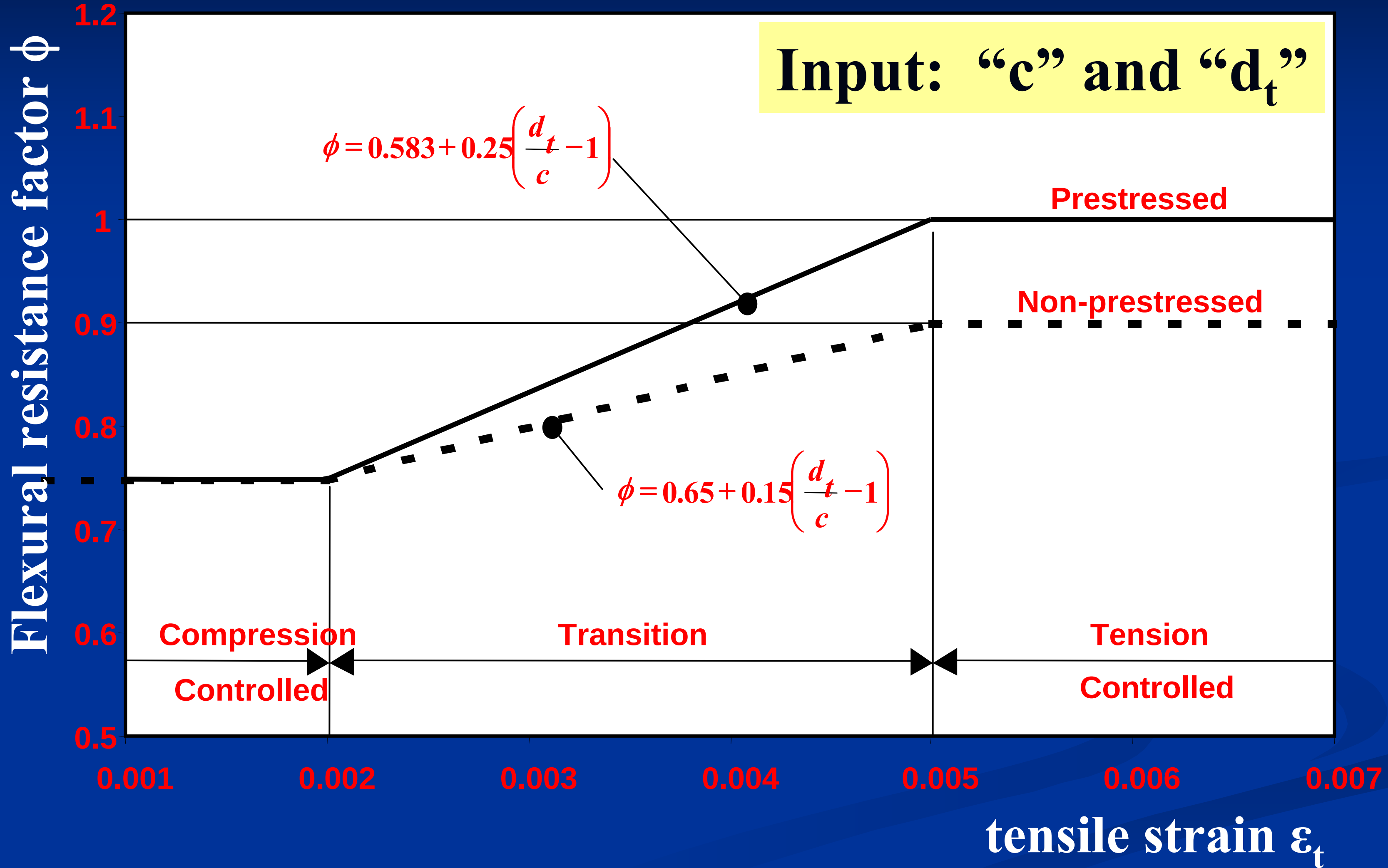
Nominal flexural Resistance - Strength



Variation of ϕ with net tensile strain ε_t and d_t/c

WA Flexural resistance factor ϕ

Item #1

Revise the second paragraph after bullets of Article 5.8.4.2 as follows:

This variation in, ϕ, may be computed for ~~prestressed~~ **precast** members such that:

$$\left(0.75 < \phi = 0.583 + 0.25\left(\frac{d_t}{c} - 1\right)\right) \leq 1.0 \quad (5.5.4.2.1\text{-}1)$$

for ~~nonprestressed~~ **cast-in-place** members such that:

$$\left(0.75 < \phi = 0.65 + 0.15\left(\frac{d_t}{c} - 1\right)\right) \leq 0.9 \quad (5.5.4.2.1\text{-}2)$$

for precast spliced girders with cast-in-place closures such that:

$$\left(0.75 < \phi = 0.616 + 0.20\left(\frac{d_t}{c} - 1\right)\right) \leq 0.95 \quad ???? \quad (5.5.4.2.1\text{-}3)$$

Item #1

ADD the following to C5.5.4.2 adjacent to Equations 5.5.4.2.1-3

The capacity reduction factor for partially prestressed members in the transition zone between tension-controlled and compression-controlled members, ϕ, may be linearly interpolated between the values for prestressed and non-prestressed members. Equation 1 and 2 may be combined and simplified. The variation in ϕ, may be computed as:

$$0.75 \leq \phi = 0.65 + 0.15\left(\frac{d_t}{c} - 1\right) + (PPR)\left[0.1\left(\frac{d_t}{c} - 1\right) - 0.067\right] \leq 0.9 + 0.1(PPR)$$

(C5.5.4.2.1-1)

Interface Shear

Correction SIP Deck Panels

$$V_n = c\,A_{cv} + \mu\,[A_{vf} f_y + P_c]$$

5.8.4.3 Cohesion and Friction Factors

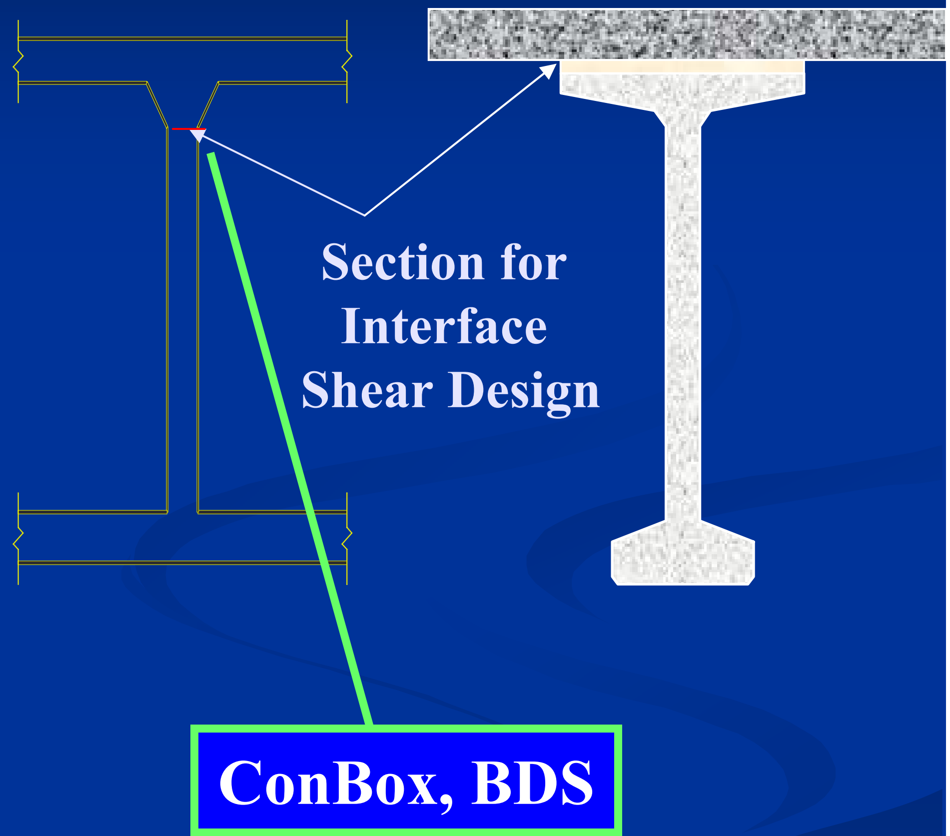
The following values shall be taken for cohesion, c, and friction factor, μ:

- For a cast-in-place concrete slab on clean concrete girder surfaces, free of laitance with surface roughened to an amplitude of 0.25-in.

  $c = 0.28$ ksi
  $\mu = 1.0$
  $K_1 = 0.3$
  $K_2 = 1.8$ ksi for normal weight concrete
  $= 1.3$ ksi for lightweight concrete

- For normal weight concrete placed monolithically

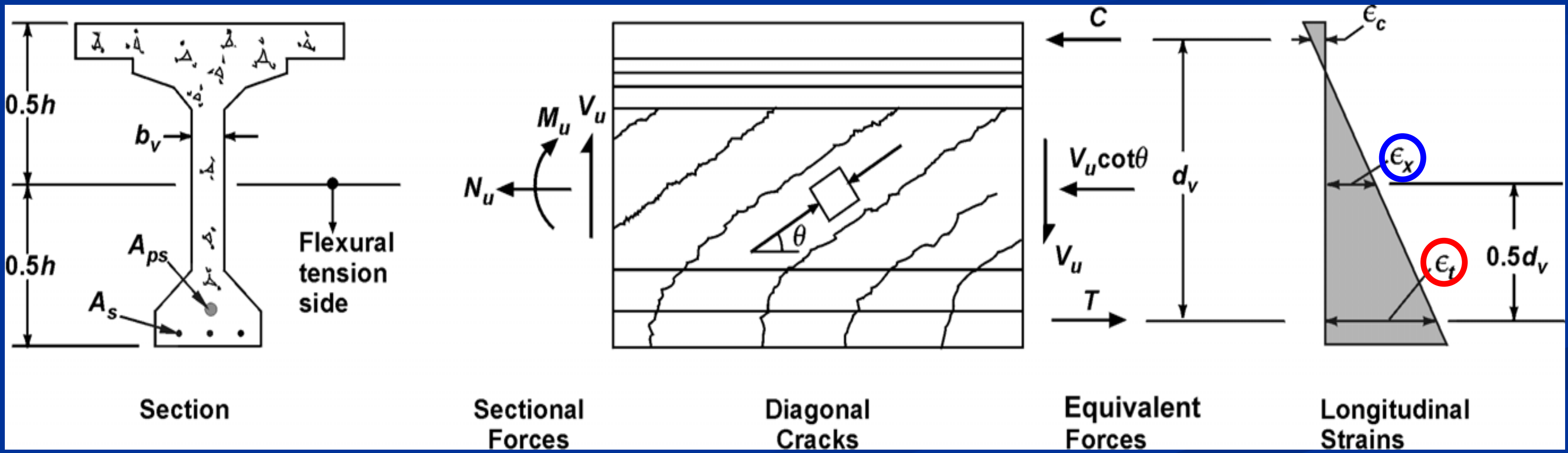
  $c = 0.40$ ksi
  $\mu = 1.4$
  $K_1 = 0.25$
  $K_2 = 1.5$ ksi



Shear Design ~ Sectional Model
Modified Compression Field Theory

Sectional analysis / design method:

- Valid where plane sections remain plane
- Sections away from “disturbed” zones



Shear Design ~ Sectional Model

Modified Compression Field Theory

WSDOT Designs:

NO: V_{ci} , V_{cw}

(5.8.3.4.3 simplified procedure)

Continue with MCFT

Review the New Equations for β and θ

$\frac{v}{f'_c}$	ε_x x 1,000								
	[illegible]0.20	≤-0.10	≤-0.05	≤0	≤0.125	≤0.25	≤0.50	≤0.[illegible]	≤1.00
≤0.075	22.3 6.32	20.4 4.[illegible]5	21.0 4.10	21.8 3.75	24.3 3.24	26.6 2.94	30.[illegible] 2.59	33.7 2.38	36.4 2.23
≤0.100	18.1 3.79	20.4 3.38	21.4 3.[illegible]4	22.5 3.14	24.9 2.91	27.[illegible] 2.75	30.8 2.50	34.0 2.32	36.7 2.18
≤0.125	19.9 3.18	21.9 2.99	22.8 2.94	23.7 2.[illegible]	25.[illegible] 2.74	27.9 2.62	31.4 2.42	34.4 2.26	37.0 2.13
≤0.150	21.6 2.88	23.3 2.79	24.2 2.78	2[illegible].0 2.72	[illegible]6.9 2.6[illegible]	28.8 2.52	32.1 2.36	34.9 2.21	37.3 2.08
≤0.175	23.2 2.73	24.7 2.66	25.5 2.65	26.2 2.60	28.0 2.52	[illegible].7 2.4[illegible]	32.7 2.28	35.2 2.14	36.8 1.96
≤0.200	24.7 2.63	26.1 2.59	26.7 2.52	27.4 2.51	29.0 2.43	30.6 2.37	3[illegible].8 2.14	34.5 1.94	36.1 1.79
≤0.225	26.1 2.53	27.3 2.45	27.9 2.42	28.5 2.40	30.0 2.34	30.8 2.14	32.3 1.86	34.0 1.73	35.7 1.64
≤0.250	27.5 2.39	28.6 2.39	29.1 2.33	29.7 2.33	30.6 2.12	31.3 1.93	32.8 1.70	34.3 1.58	35.8 1.50

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- The shear design of all **non-prestressed** members shall be based on the simplified procedure of LRFD using shear parameters of:

  $\beta=2.0$

  $\theta=45^{o}$

- Strut-and-Tie model **May be** considered as Required by LRFD for:
  - Pile caps and shaft caps
  - Crossbeams and diaphragms
  - Post-tensioning anchorages
  - Other Members where Beam Theory Does not Apply

Damaged Girders by Over-height Load Collision

WSU RESEARCH PROJECT:

Impact Resistance of Prestressed girders (Effect of Intermediate Diaphragms)

**Parameters: Bridge Geometry, Framing Plan,
Diaph. Depth, Stiffness, Location,**

Effect of Intermediate Diaphragms

Bottom Flange Rotation of Exterior Girders Due to Lack of Restraint Provided by the Intermediate Diaphragms

New Pretensioned Trapezoidal Girders

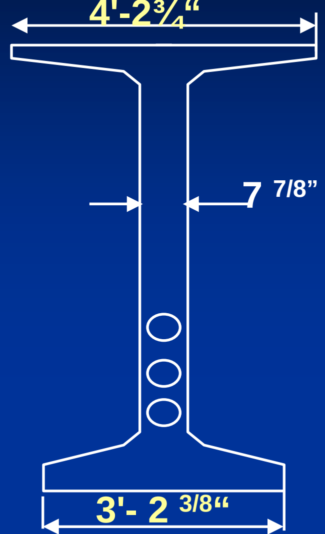
Need for Int. Diaphragms

Elastomeric Bearings

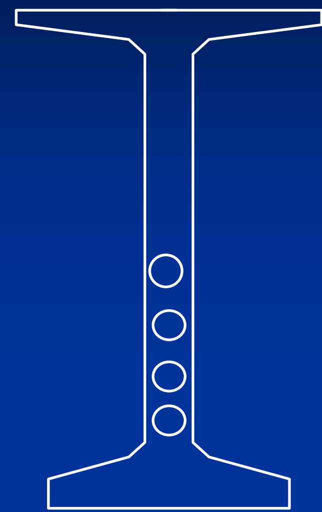
SPLICED-GIRDER CONSTRUCTION METHODS

Post-Tensioning Before Slab Casting	Post Tensioning After Slab Casting
Cast Wet Joints and Apply PT	Place Segments and Cast Wet Joints
Erect Assembled Girder	Apply PT
Cast Deck Slab and Traffic Barriers	Cast Traffic Barriers

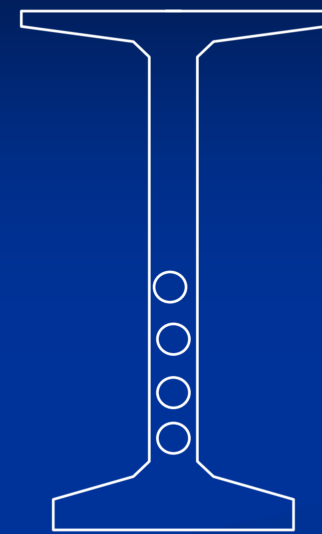
PRECAST SUPERSTRUCTURE: PT SPLICED I-GIRDERS



WF74PTG



WF83PTG

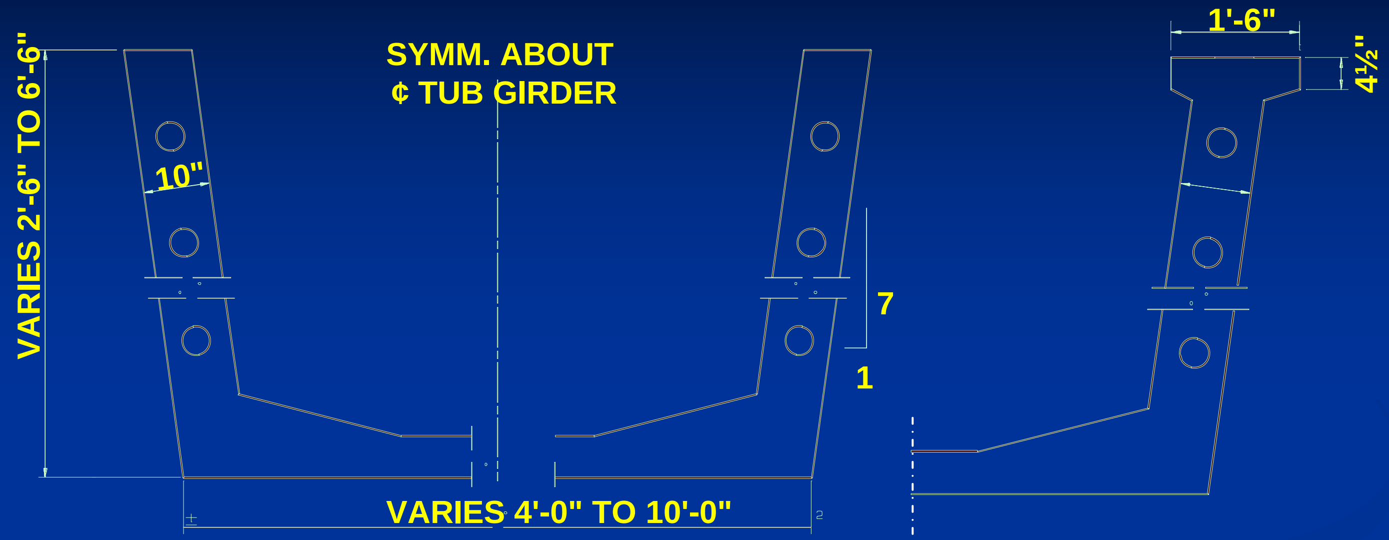


WF95PTG

Old 4-Span Existing Bridge

New 1-Span Bridge

PRECAST SUPERSTRUCTURE: PT SPLICED U-GIRDERS



TRAPEZOIDAL TUB SECTION

Span Capability, ft	
U54PTG6	145
U66PTG6	165
U78PTG6	190

Spliced-Girder Closures

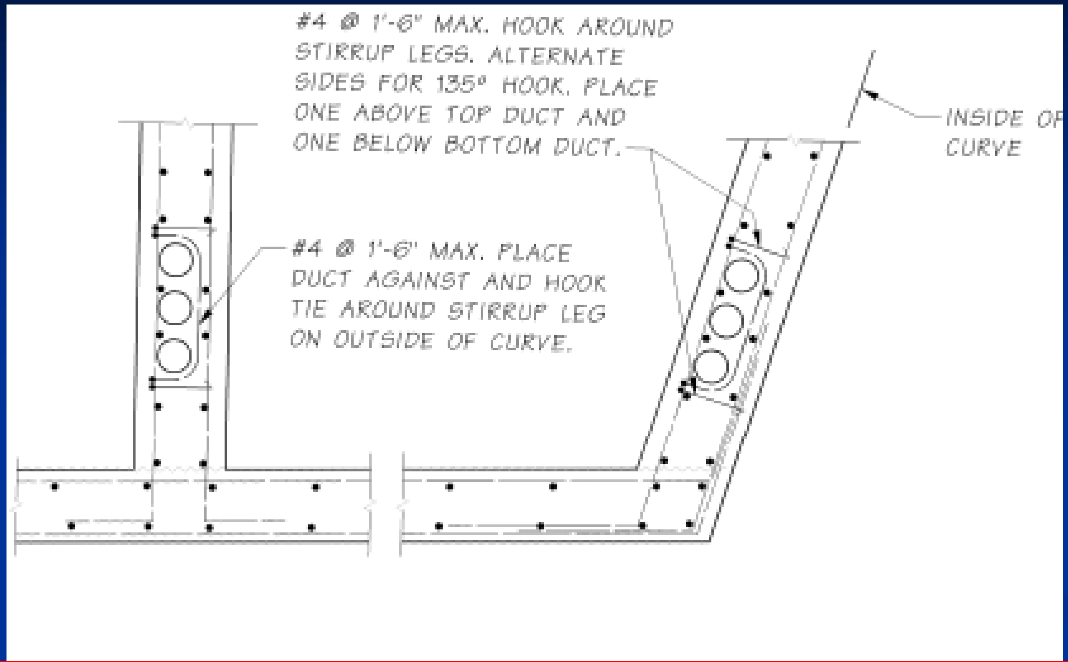
- 2 ½ in concrete cover at the CIP closures at piers
- Side forms to be removed prior to Post-Tensioning
- 2 in clear spacing between ducts at CIP closures

Curved PT Girders

- The effects of in-plane and out-of-plane forces of curved tendons shall be investigated during the design of post-tensioned bridges
- When tendons curve in two planes, the effects of in-plane and out-of-plane forces shall be added.
- Supplemental ties shall be provided to confine the PT tendons when horizontal curvature radius is less than 800 ft or the effect of in-plane and out-of-plane forces exceeds the limit shown below:

$$\frac{P_u}{R}\left(1+\frac{1}{\pi}\right)\geq 10 \quad \text{k/ft}$$

Curved PT Girders



Tendon confinement reinforcement:

- **#4 bars at 1’-6” max, wrapping PT ducts, hook around stirrups on outside of curve**
- **#4 web ties at 1’-6” max, hooked around stirrups placed on above and below ducts**

Cast-in-Place Concrete girders

Problems:

- ✓ Larger Span to Depth Ratio
- ✓ Design Deficiency (LFD vs. ASD)
- ✓ Creep effect Cracking at Piers

Design Policy Memorandum

Restriction on CIP-Concrete Girders

- PT shall be considered for all new CIP - RC single or multi-span box girder bridges.
- Partial Prestressing shall not be considered for design of RC box girders.
- CIP reinforced concrete girders could be used only for widening of existing RC box girders
- CIP reinforced concrete girders may be used for bridges with tight curvatures

Concrete Deck Slabs

Problem:

- **Deck Cracking - Top and bottom**

(Shrinkage, Concrete Mix Design, Curing, etc.)

Design Policy Memorandum

Concrete Deck Slab Reinforcement

- Epoxy coated reinf for both top and bottom layer rebar of all bridge deck slabs without longitudinal PT
- Epoxy coated reinforcement for only top layer rebar of bridge deck slabs with longitudinal PT

Future:

Increase minimum Slab Thickness to 8”

(1.5” cover to accommodate for 1” Agg. size)

Precast S-I-P Concrete Deck panels

- Precast I or Tub Girders
- 14 Days wet Curing
- One Layer Epoxy Reinf

Design Policy Memorandum

- S-I-P deck panels Could be used for bridge deck upon Bridge Office approval (The CIP Deck Remains the Preferred option)
- Min. 8.5” Slab including 3.5” S-I-P deck panel and 5.0” C-I-P slab shall be specified
- Designer shall consider the extra weight for EQ design and substructure.

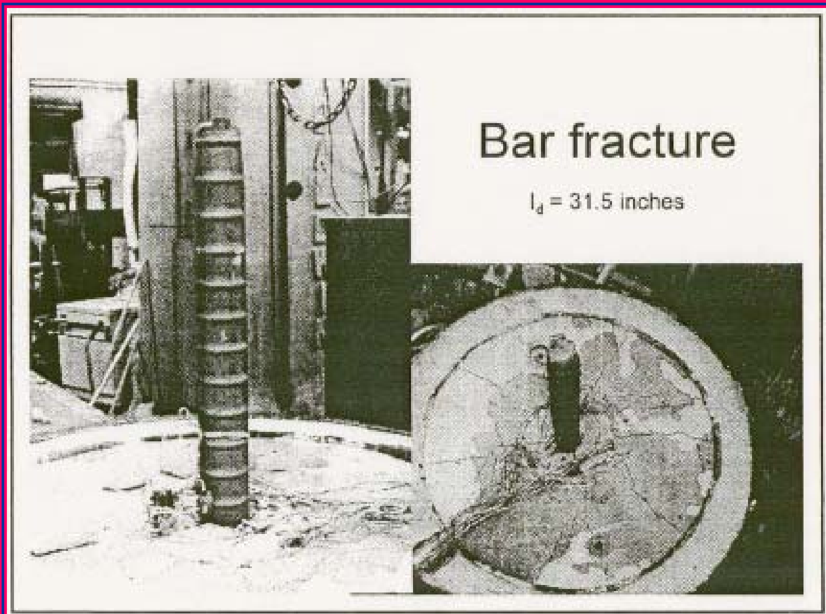
Standard SIP deck panels are:

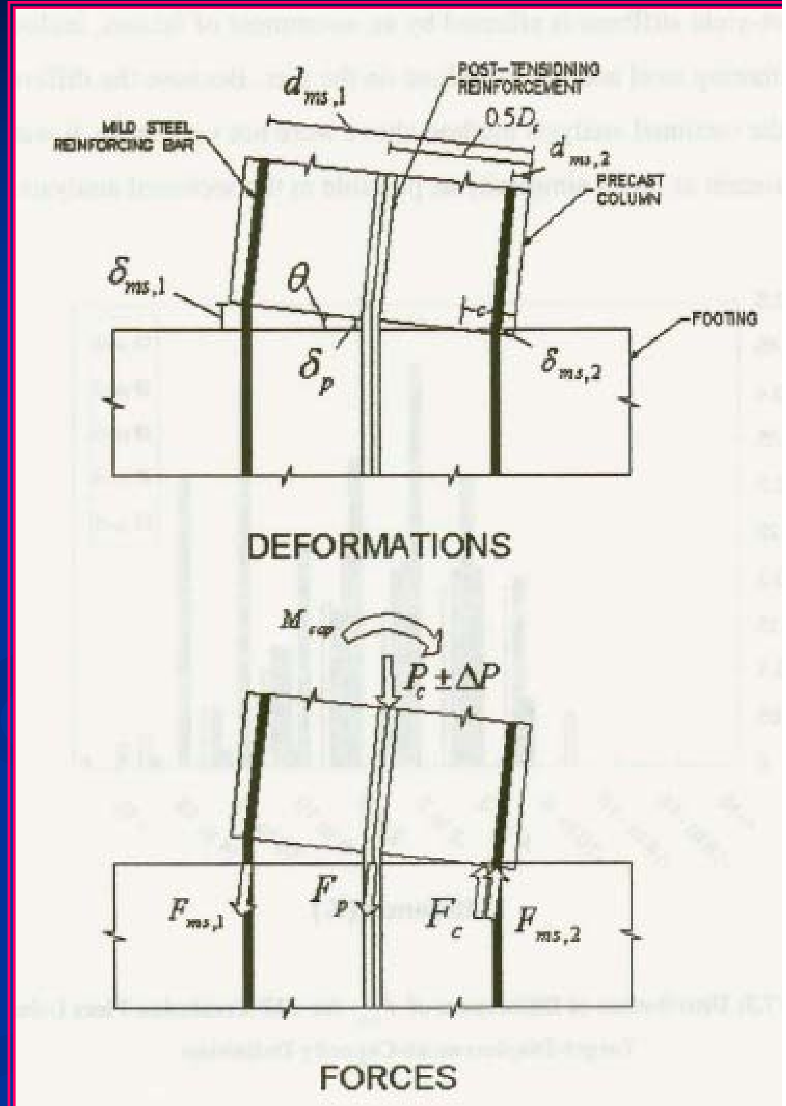
Panel Dimensions:	t = 3.5 in	w = 8.0 ft
Concrete:	7.0 ksi Release,	8.5 ksi Final
Prestressing Strands:	3/8 in. or 7/16 in.	

PRECAST SUBSTRUCTURE RESEARCH AT UW

Pull-out tests:

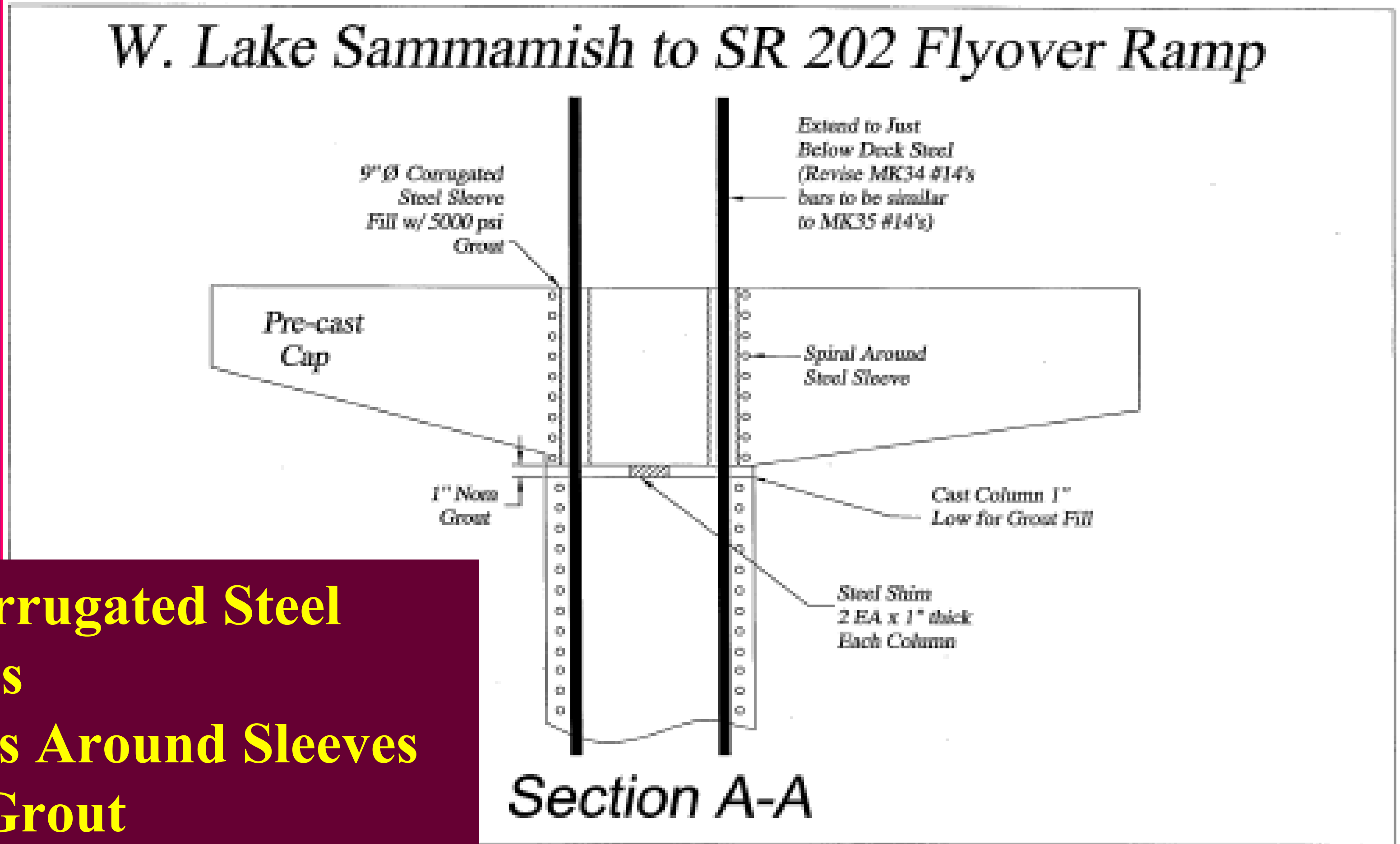
- **Bond properties and development lengths (at full scale) for #14 and #18 bars grouted in ducts**





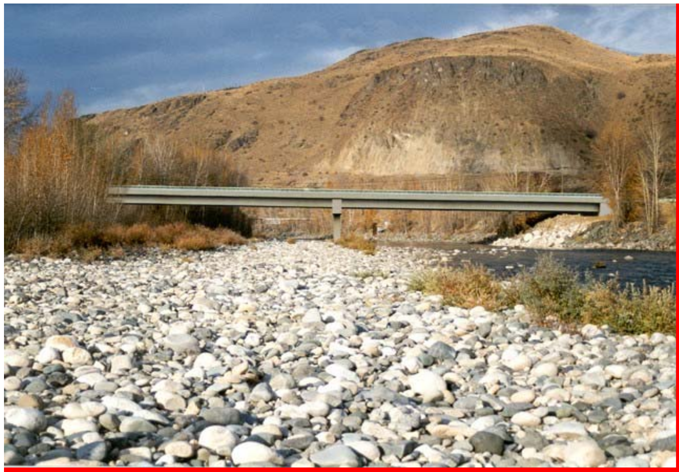
PRECAST CROSSBEAM

Crossbeam-Column Connection



- 9” Corrugated Steel Sleeves
- Spirals Around Sleeves
- 5 ksi Grout
- #14 Column Bard

PRECAST CROSSBEAM



Thank You Questions?