STRUCTURAL BEHAVIOR OF BARRIER-OVERHANG CONNECTION IN CONCRETE BRIDGES USING AASHTO LRFD METHOD

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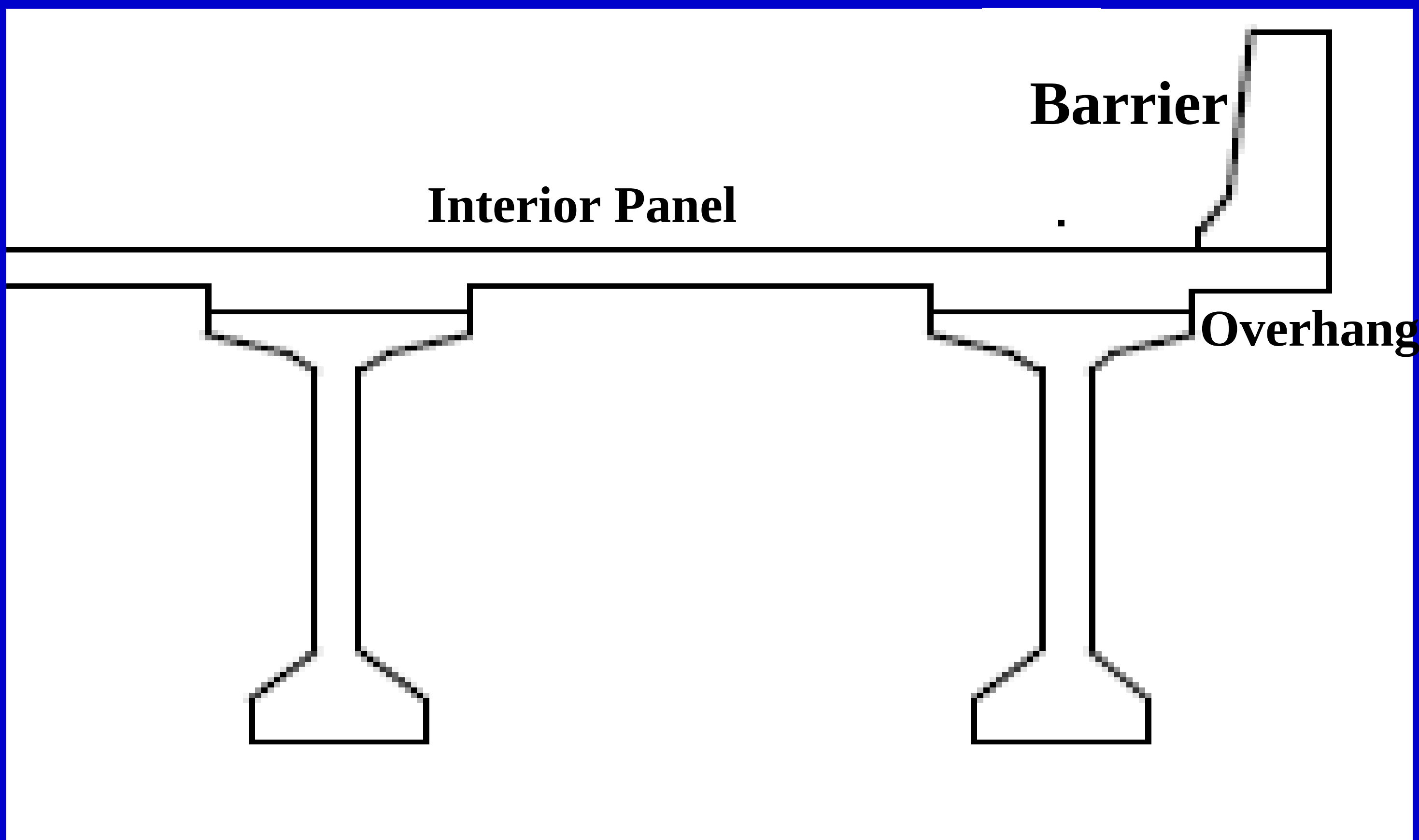
2009 Western Bridge Engineers' Seminar
Sacramento Convention Center, Sacramento, CA,
September 21-23, 2009

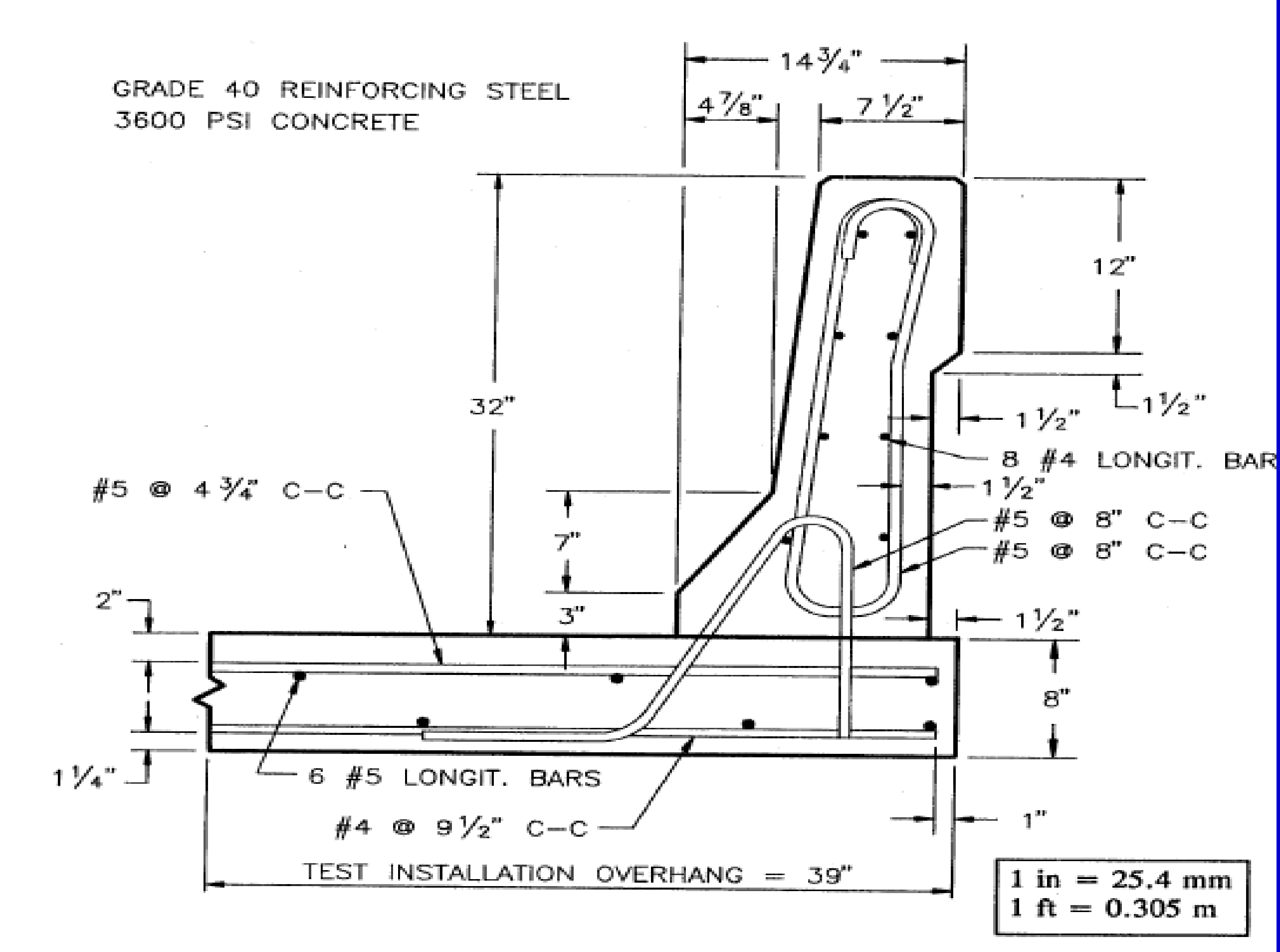
CONCRETE DECK



AAHTO LRFD
(NCHRP-350)
BARRIER TEST LEVEL REQUIREMENT

BARRIER DESIGN CHECK PROCESS

(1) SELECT THE BARRIER TEST LEVEL, GEOMETRY AND REINFORCEMENT



(2) CALCULATE BARRIER CRASH RESISTANCE BY LRFD YIELD ANALYSIS:

At Continuous Locations

$$R_w = \left(\frac{2}{2L_c - L_t}\right)\left(8M_b + 8M_w H + \frac{M_c L_c^2}{H}\right) \qquad L_c = \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + \frac{8H(M_b + M_w)}{M_c}}$$

At Ends or Joint Locations

$$R_w = \left(\frac{2}{2L_c - L_t}\right)\left(M_b + M_w H + \frac{M_c L_c^2}{H}\right) \qquad L_c = \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + H\left(\frac{M_b + M_w}{M_c}\right)}$$

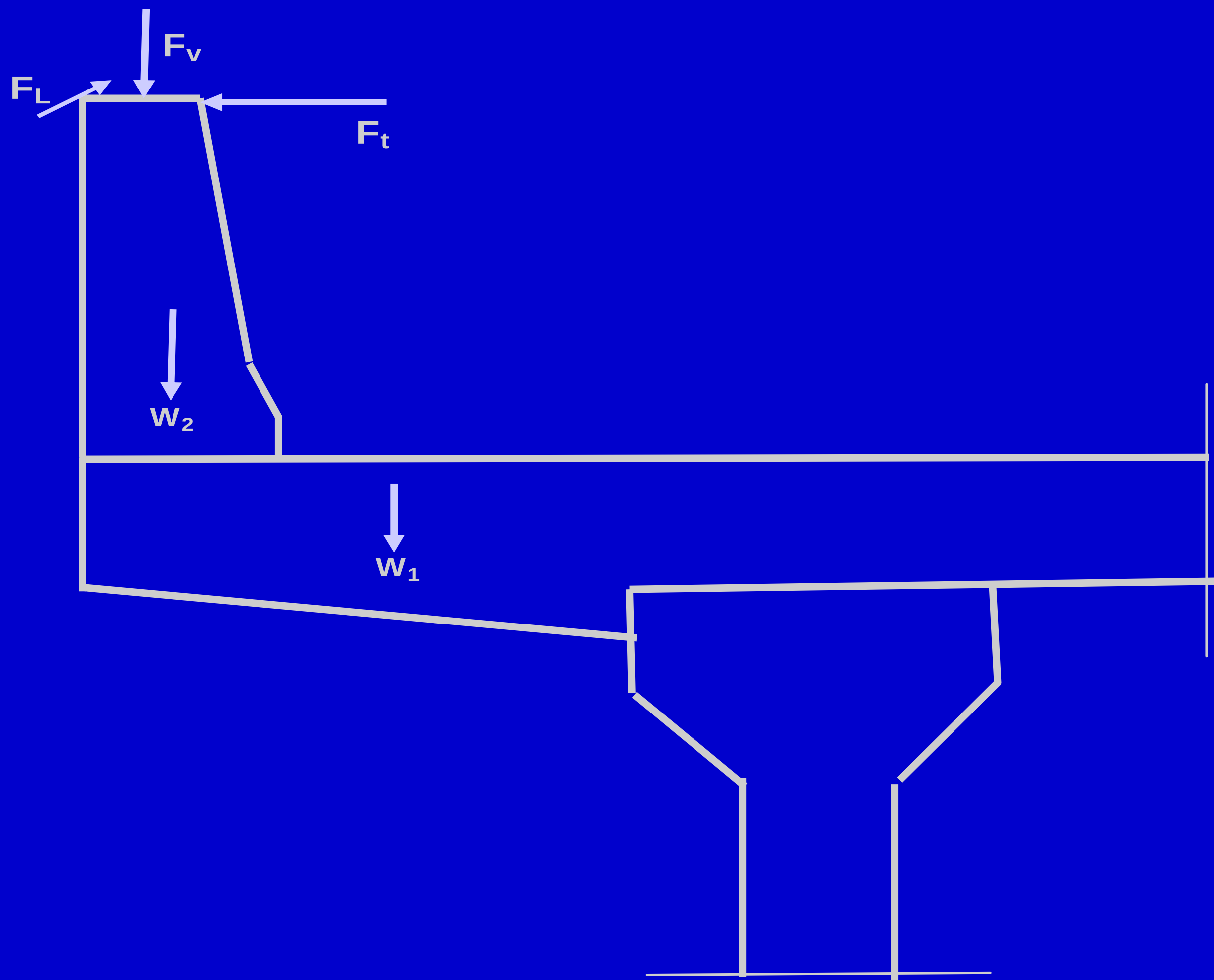
R_w = Transverse resistance of the barrier (kip)
M_c = Flexural resistance of the barrier about its longitudinal axis (kip-ft/ft)
M_w = flexural resistance of the barrier about its vertical axis (k-ft/ft)
M_b = additional flexural resistance (in addition to Mw, if any), not applicable here
L_c = critical length of yield line pattern (ft)
L_t = longitudinal distribution length (ft)
H = barrier height (ft)

(3) Compare the Calculated Resistance With the Required LRFD Crash Values (Table)
(4) Modify The Design Details if Required

Design Forces and Designations	Railing Test Levels						
	TL-1	TL-2	TL-3	TL-4	TL-5A	TL-5	TL-6
F_t Transverse (KIP)	13.5	27	54	54	116	124	175
F_L Longitudinal (KIP)	4.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58
F_v Vertical (KIP) Down	4.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80
L_t and L_L (FT)	4.0	4.0	4.0	3.5	8.0	8.0	8.0
L_v (FT)	18.0	18.0	18.0	18.0	40.0	40.0	40.0
H_e (min) (IN)	18	20	24	32	40	42	56
Minimum H Height of Rail (IN)	27	27	27	32	40	54	90

LRFD CRASH TEST LEVEL REQUIREMENT

BARRIER-DECK OVERHANG INTERACTION



DESIRED LRFD
<u>FAILURE SEQUENCE</u>
in a Crash Event

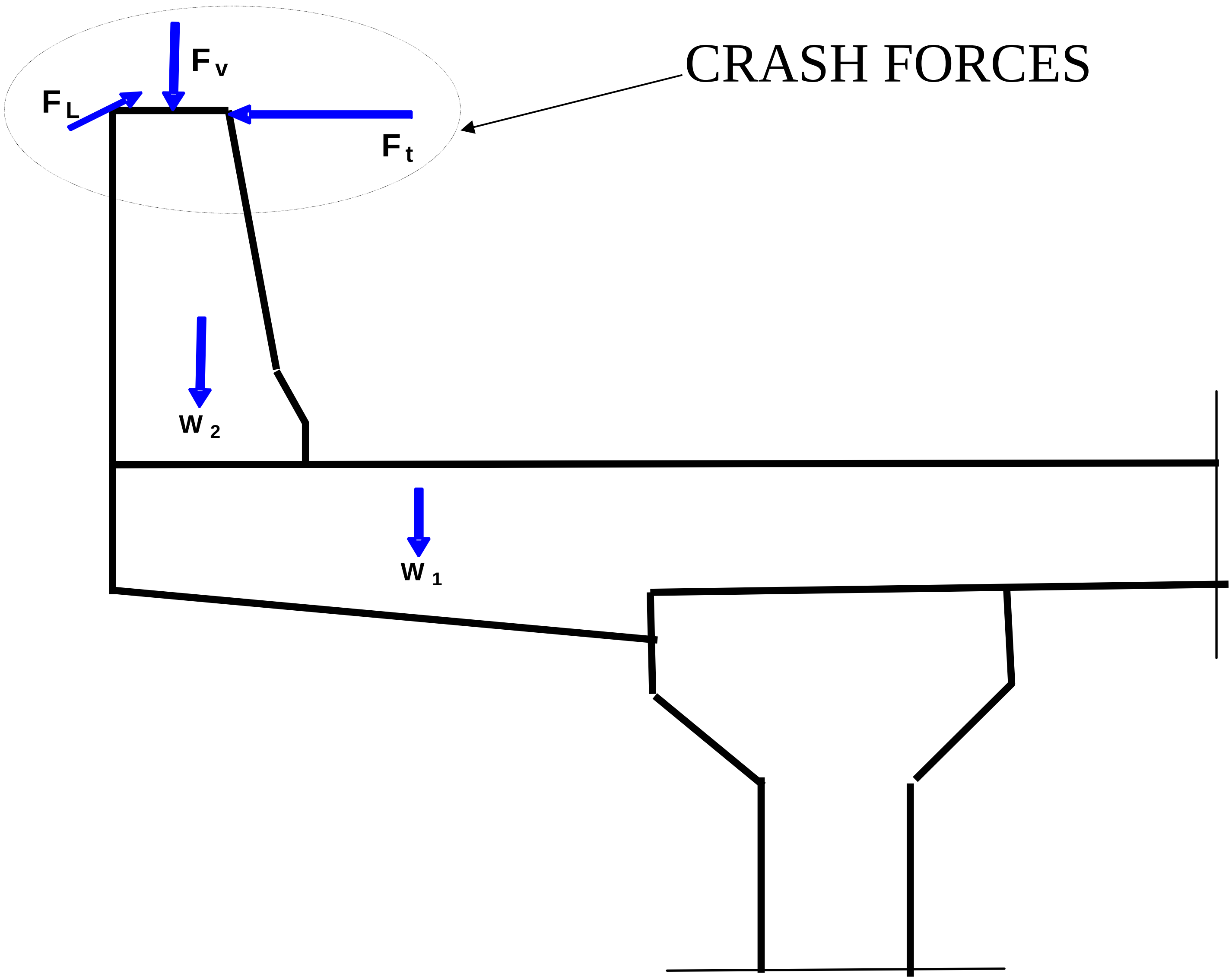
First: BARRIER
Second: OVERHANG

- ***Overhang Safely Resists the Crash***
- ***Barrier is Easier to Repair***

OVERHANG DESIGN

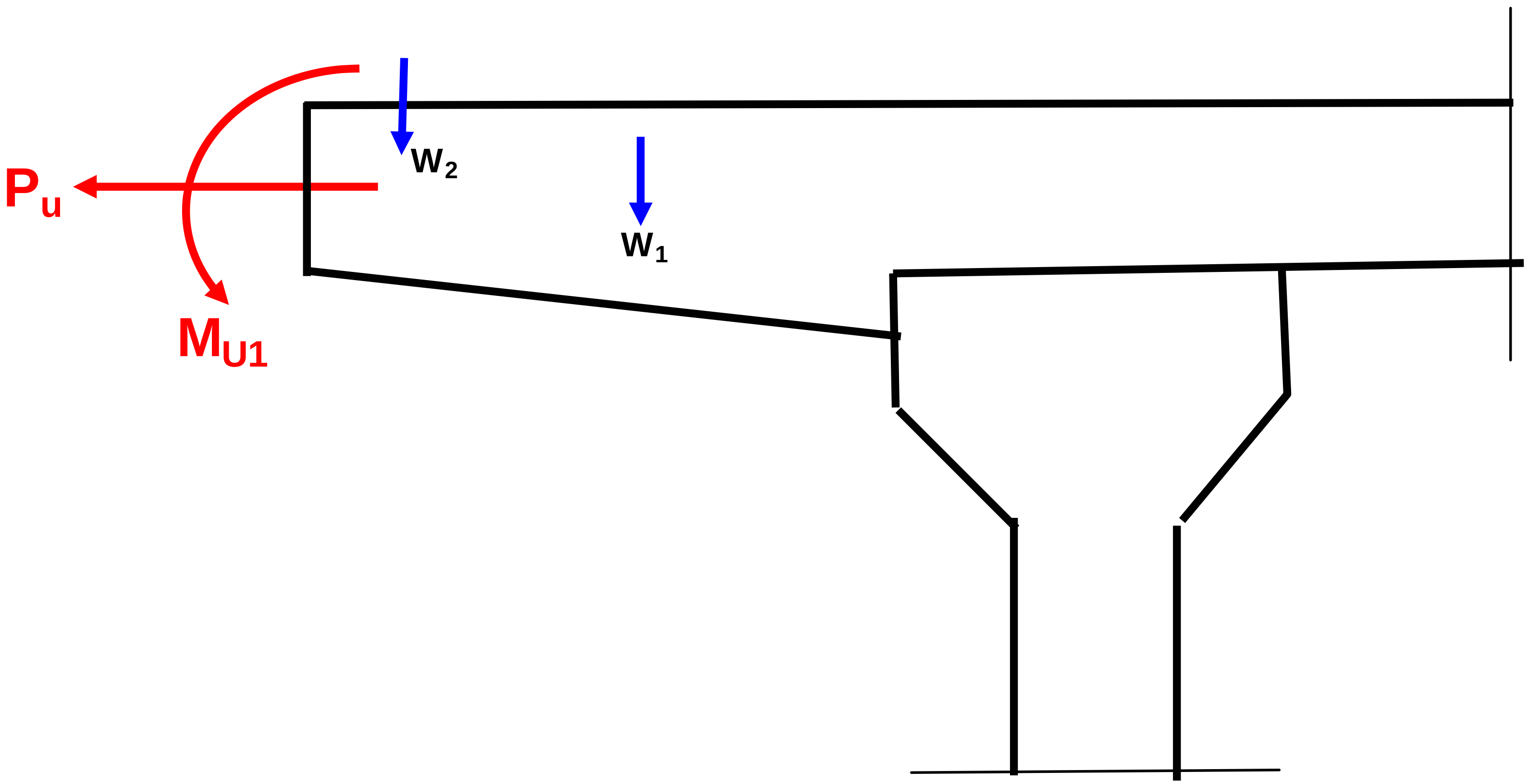
The Problem?

OVERHANG CANTILEVER SHOULD ALSO RESIST THE CRASHING FORCES FROM THE BARRIER

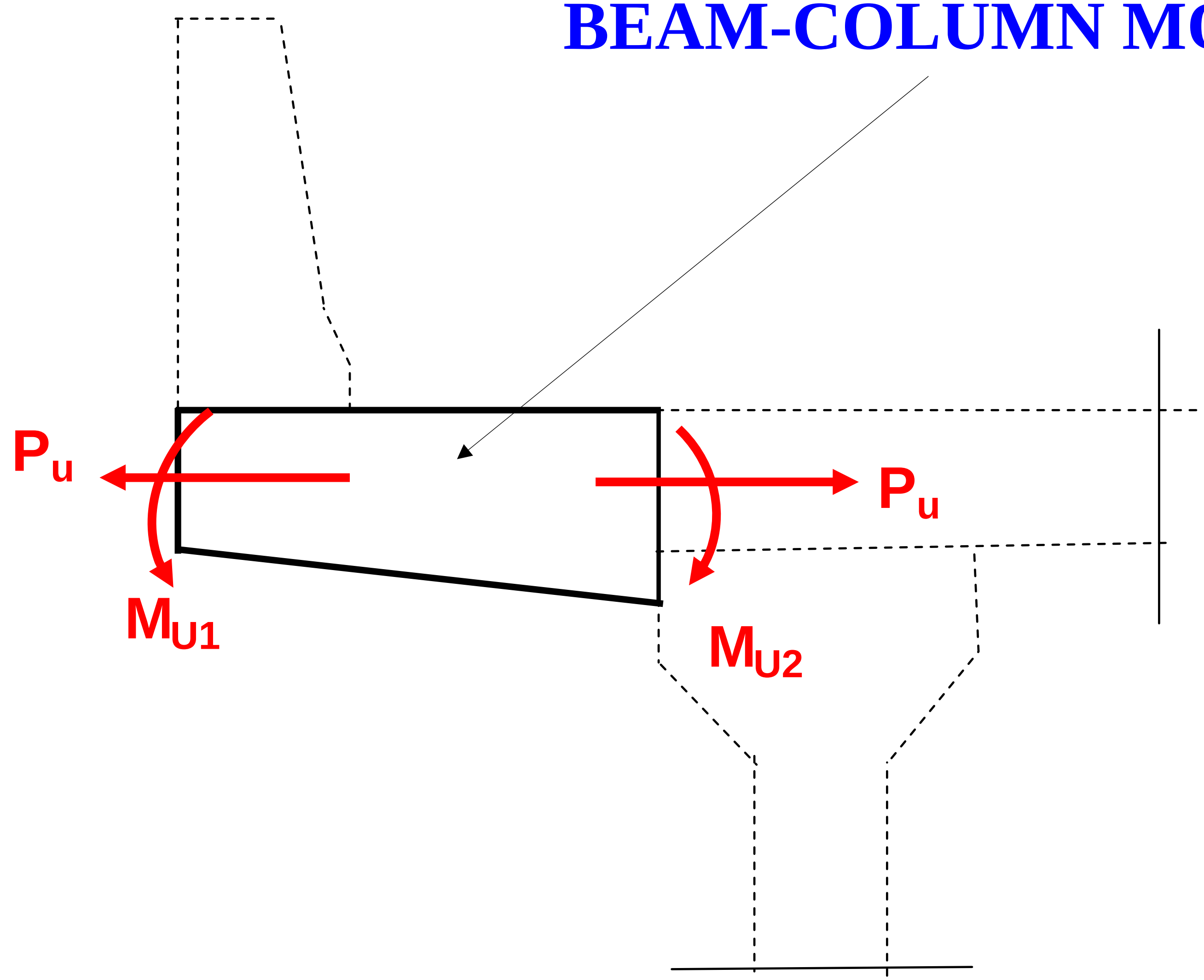


CRASH FORCES
F L
F v
F t
W 2
W 1

M_{u1} , P_u = CRASH FORCE REACTIONS TO OVERHANG

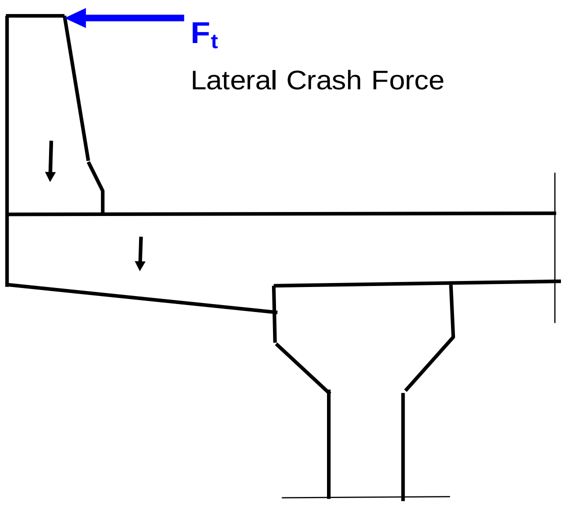


BEAM-COLUMN MODEL



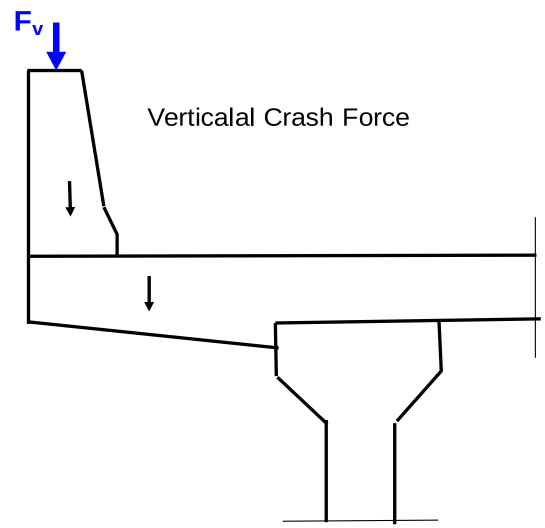
LRFD
LOAD COMBINATIONS

LRFD LOAD COMBINATIONS



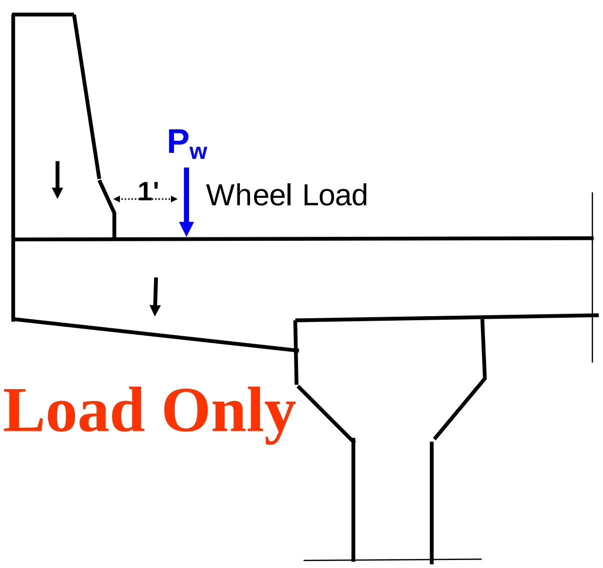
Extreme Event II for F_t

(Continuous or Joint Location)



Extreme Event II for F_v

(Continuous or Joint Location)

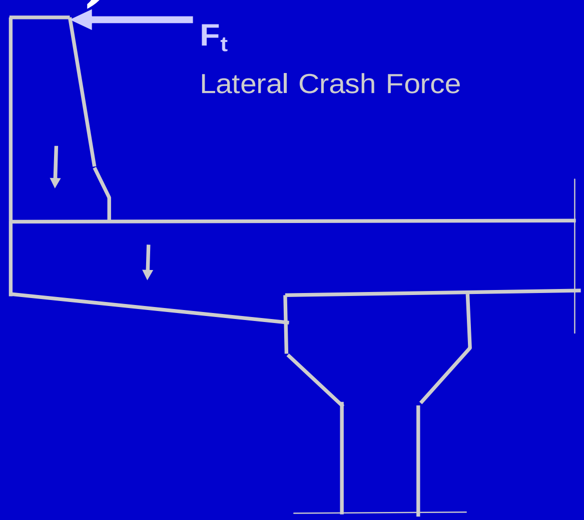


Strength I, Wheel Load Only

Extreme Event II for F_t

All Load Factors=1

Barrier: Continuous, Ends (Joints) Location



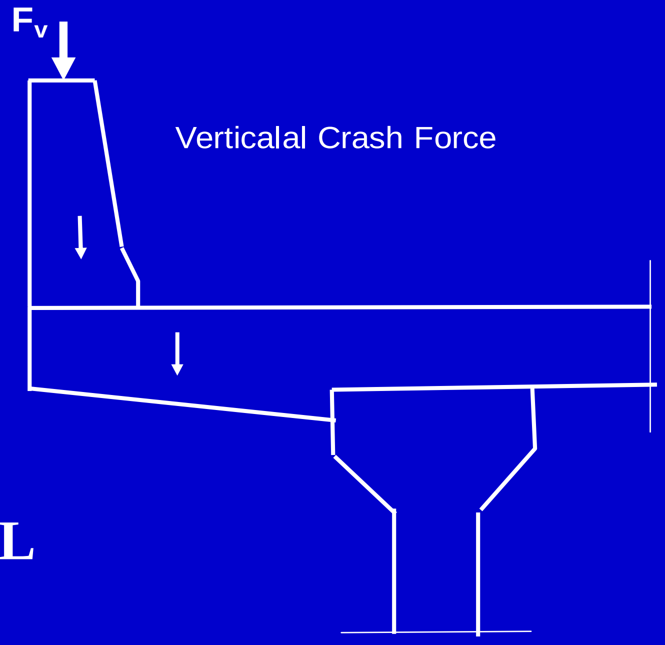
Forces:

- **Transverse Crash Force F_t**
- **Longitudinal Crash Force F_L**
- **Dead loads, FWS**

Overhang is Subject to Moment + Tension

Extreme Event II for F_v

(All Load Factors=1)

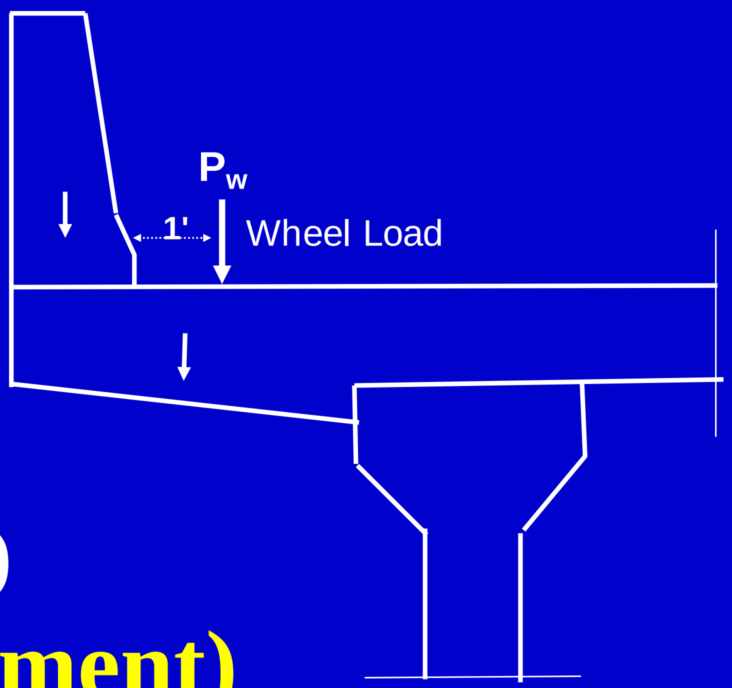


Forces:

- **Vertical Crash Force, Fv**
- **Longitudinal Crash Force F_L**
- **Dead Loads, FWS**

Overhang Subject to Moment Only

Strength I



Wheel Load (LL)
Dead Loads (DC)
FWS Load (DW)
1.25(DC)+1.5(DW)+1.75(LL)

(Overhang Subject to Moment)

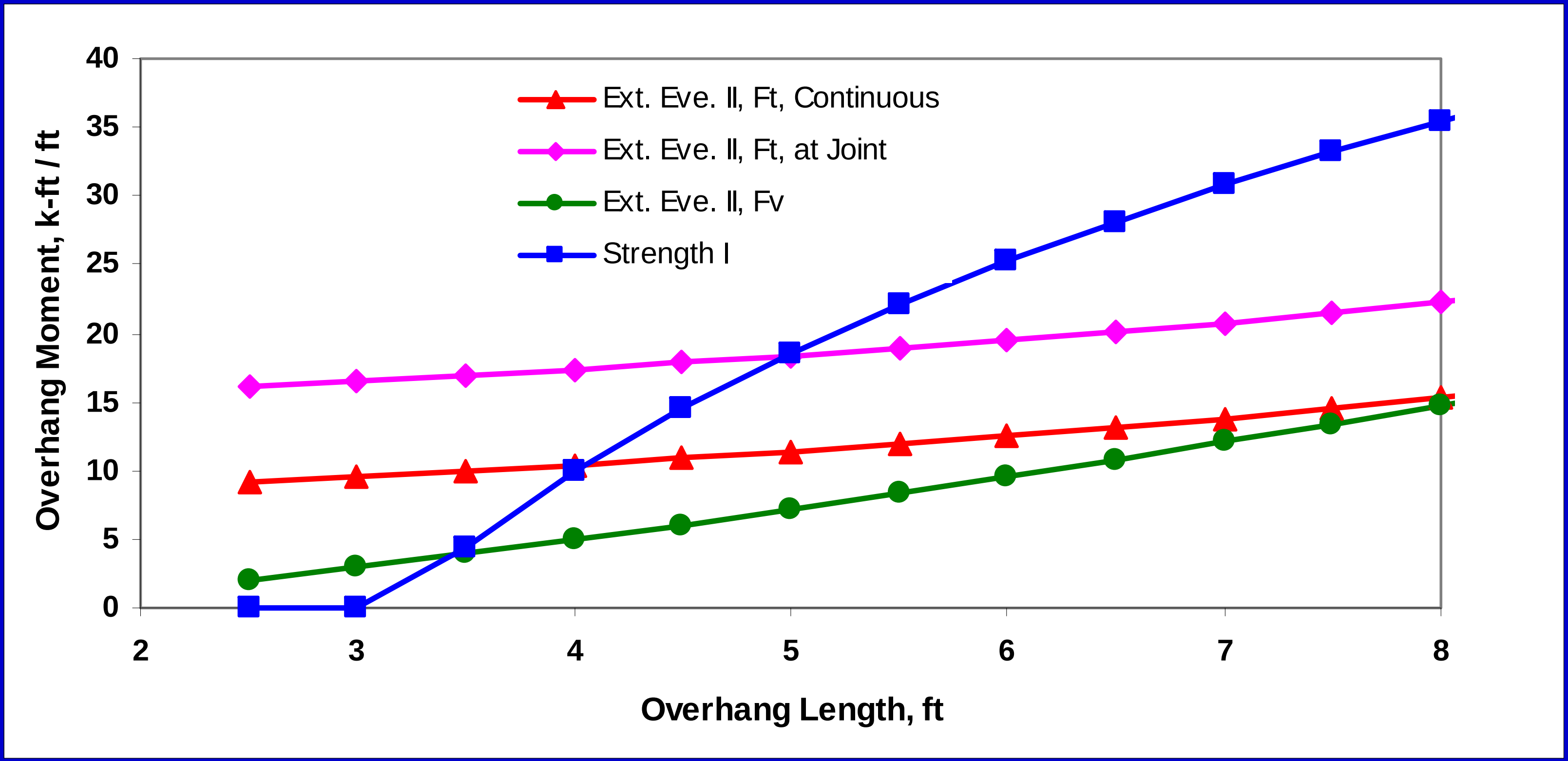
Conventional Wheel Load Method

Example Design Forces For Overhang

(5’ Overhang with TL-4 Crash Force)

LOAD COMBINATION	Tensile Force, P_u Kip (per foot)	Bending Moment, M_u K-ft (per foot)
Extreme Event II, F_t , Continuous	3.2	11.1
Extreme Event II, F_t , Ends or Joint	5.2	18.1
Extreme Event II, F_v , Continuous Location	0	8.0
Strength I, Wheel Load Only	0	12.2

OVERHANG LOAD COMBINATION COMPARISON

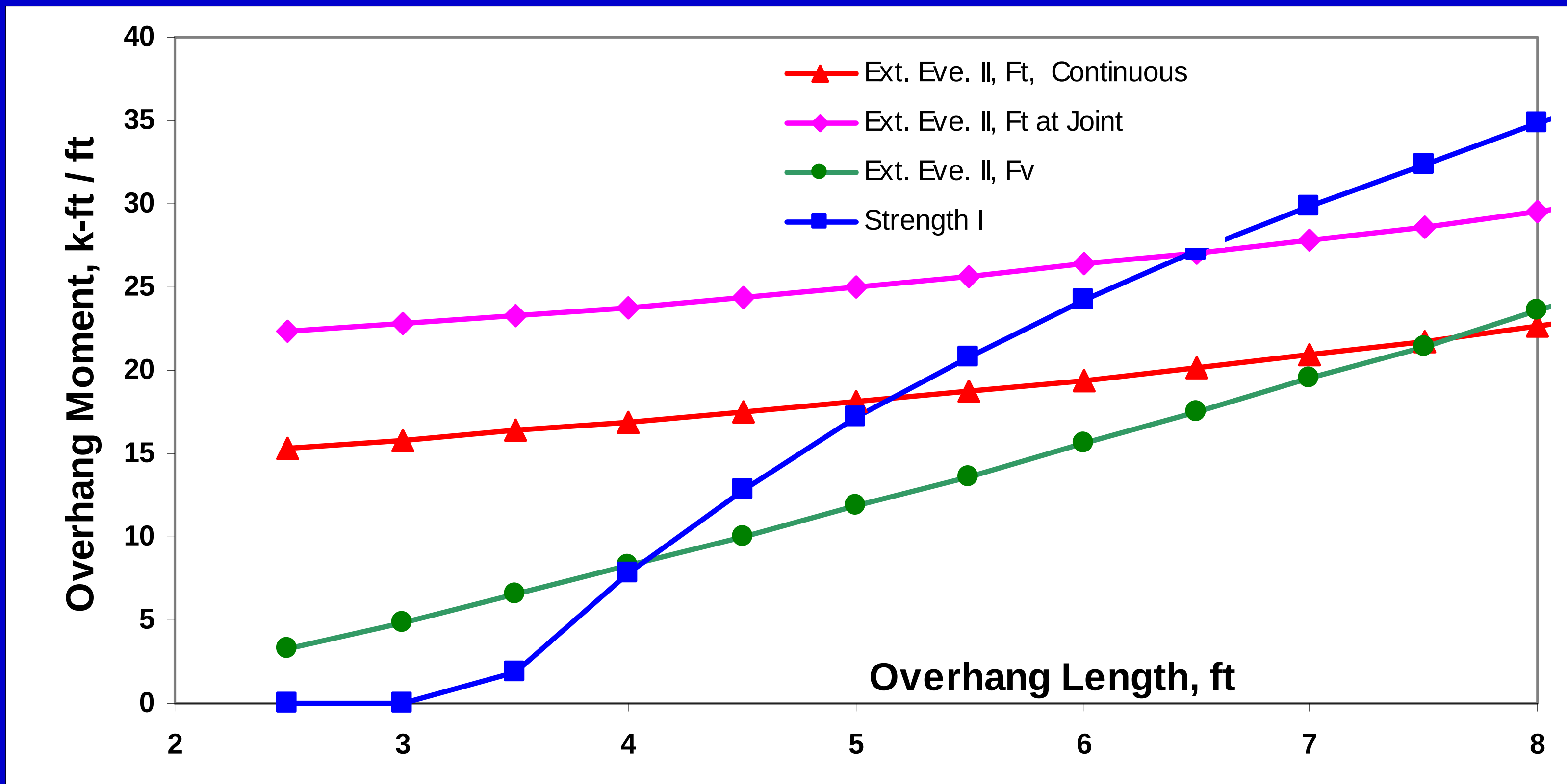


32" Barrier with TL-4

Note:

The First Two Combinations are Associated with Axial Tension F_t

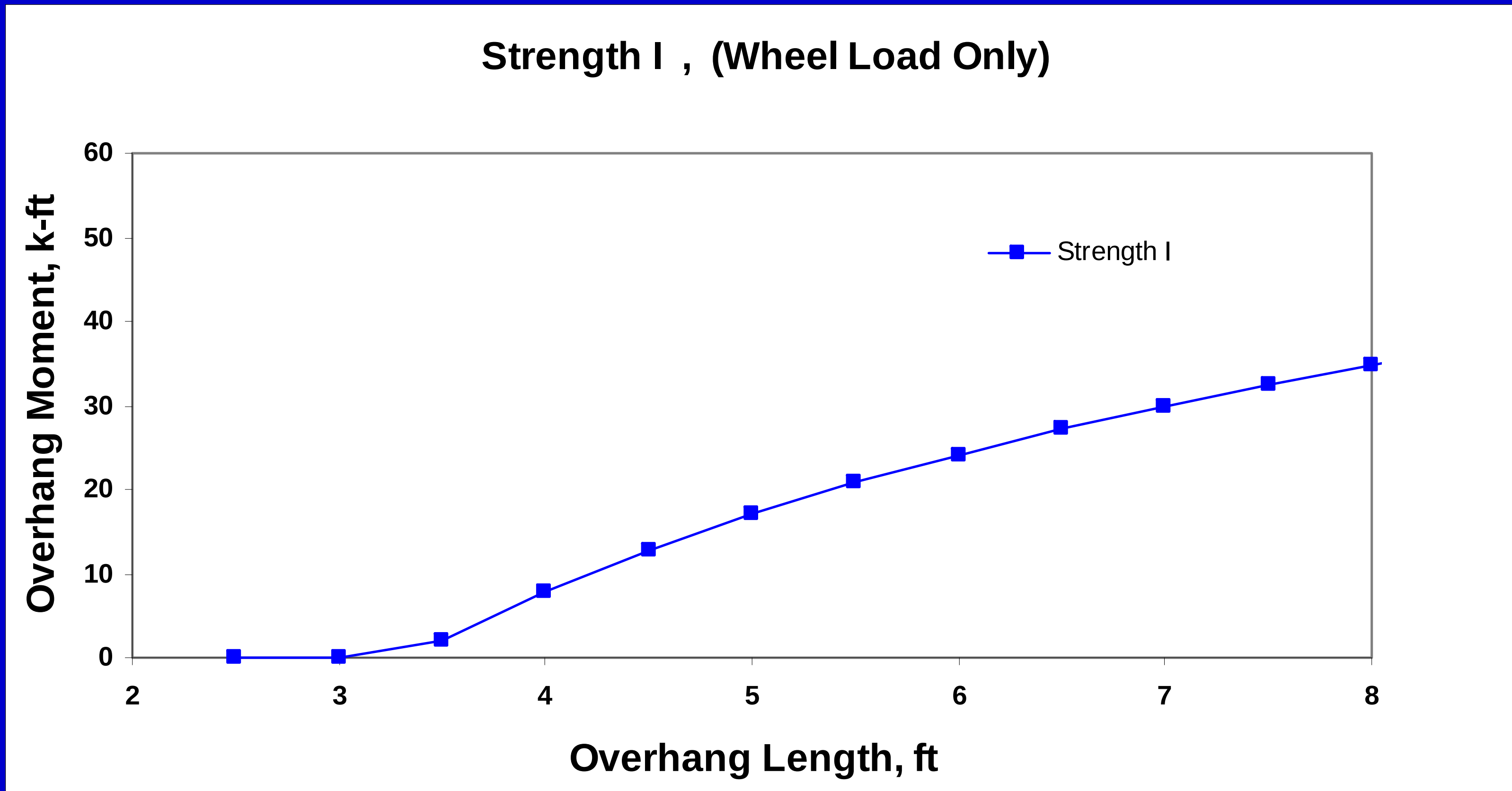
OVERHANG LOAD COMBINATION COMPARISON

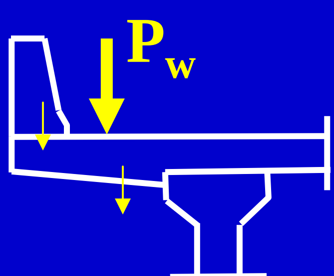


42" Barrier with TL-4

Note:

The First Two Combinations are Associated with Axial Tension F_t

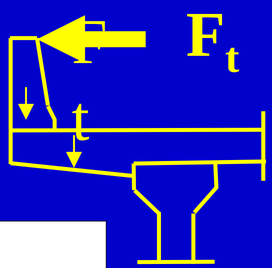


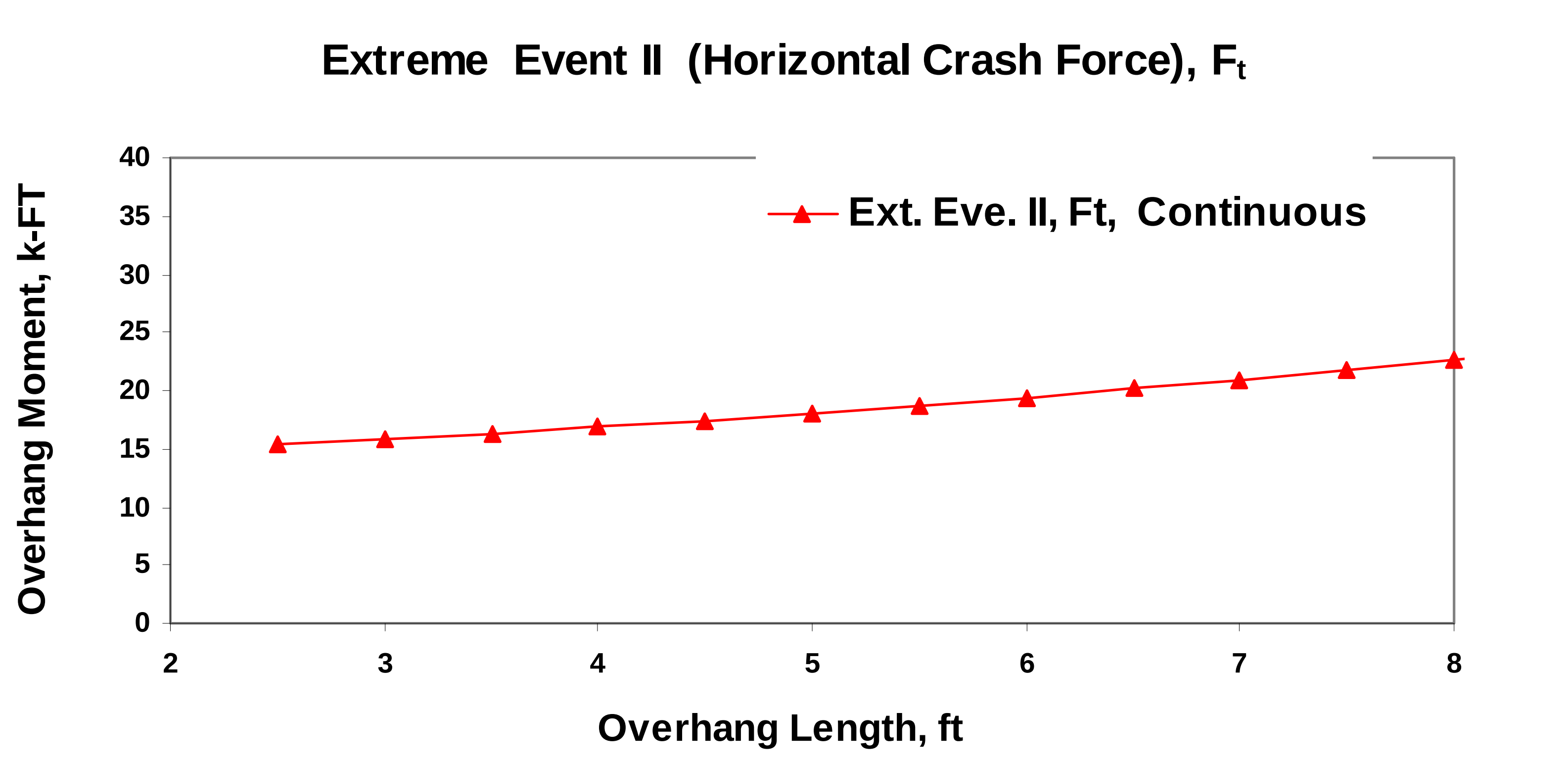


OLD (STANDARD) METHOD:

DESIGN THE OVERHANG FOR WHEEL LOAD MOMENT

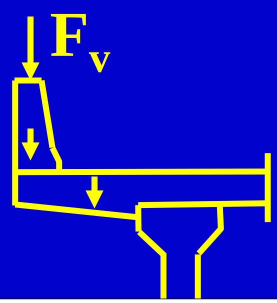
LRFD Extreme Event With CRASH HORIZONTAL FORCE

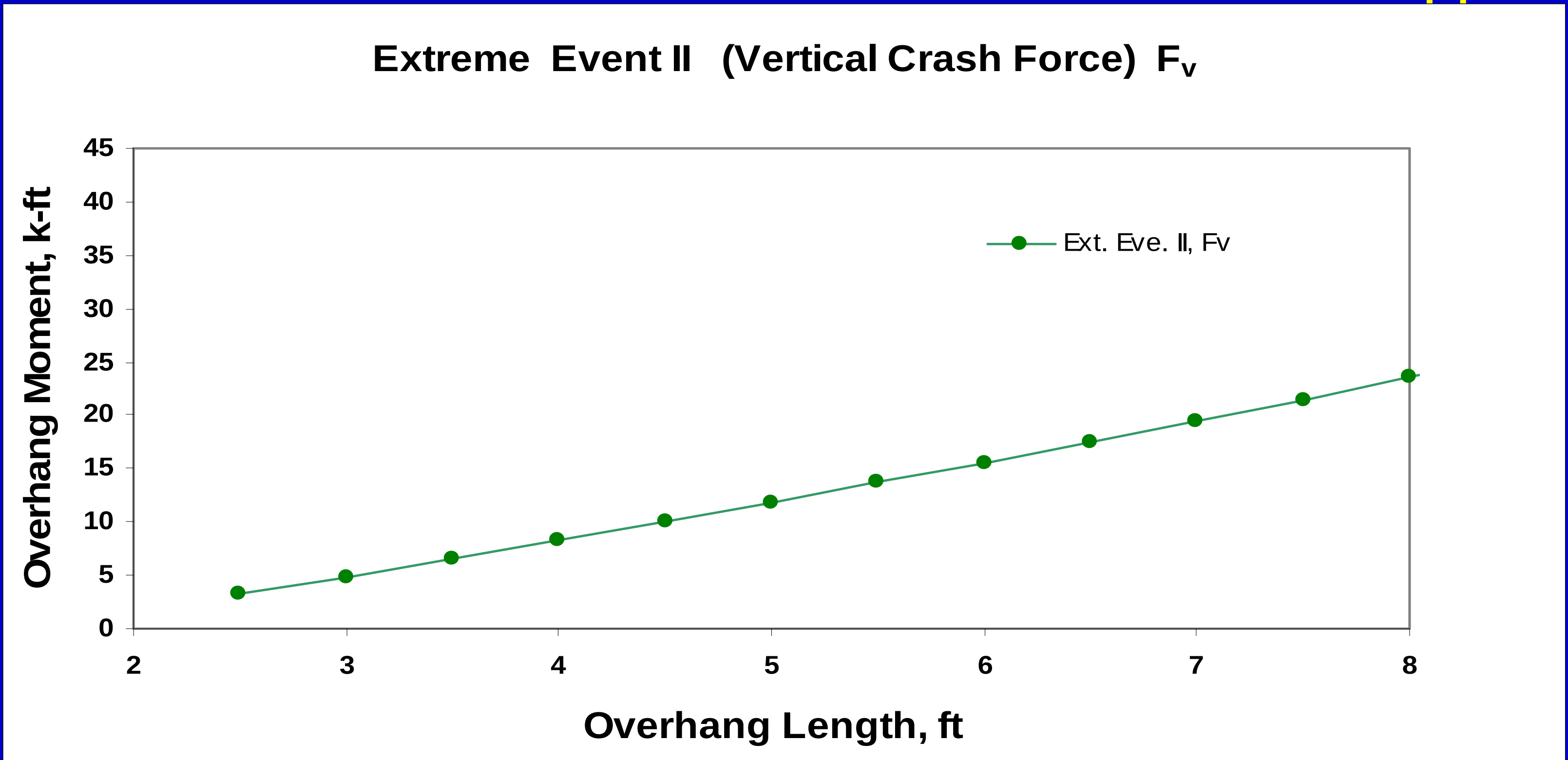




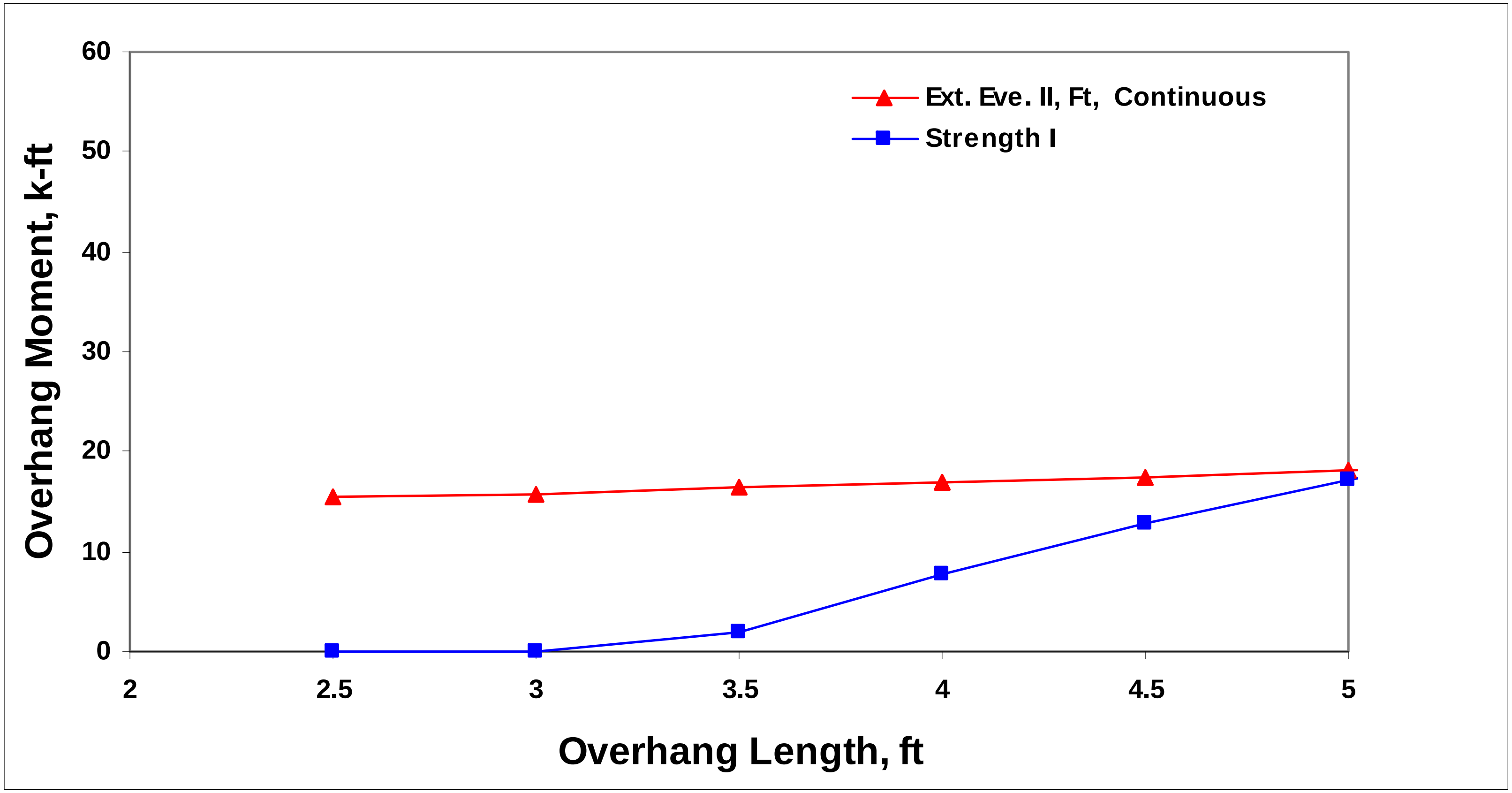
Overhang Subject to Moment +Tension
Moment is Almost Constant Along Overhang
A Hunch can not Optimize the Design

LRFD Extreme Event With
CRASH VERTICAAL FORCE

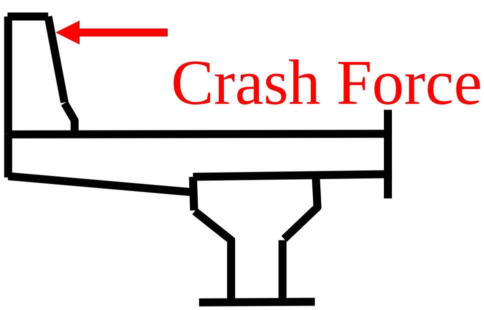


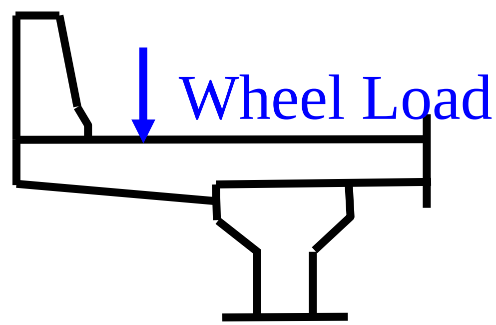


OVERHANG IS SUBJECT TO:
MOMENT ONLY



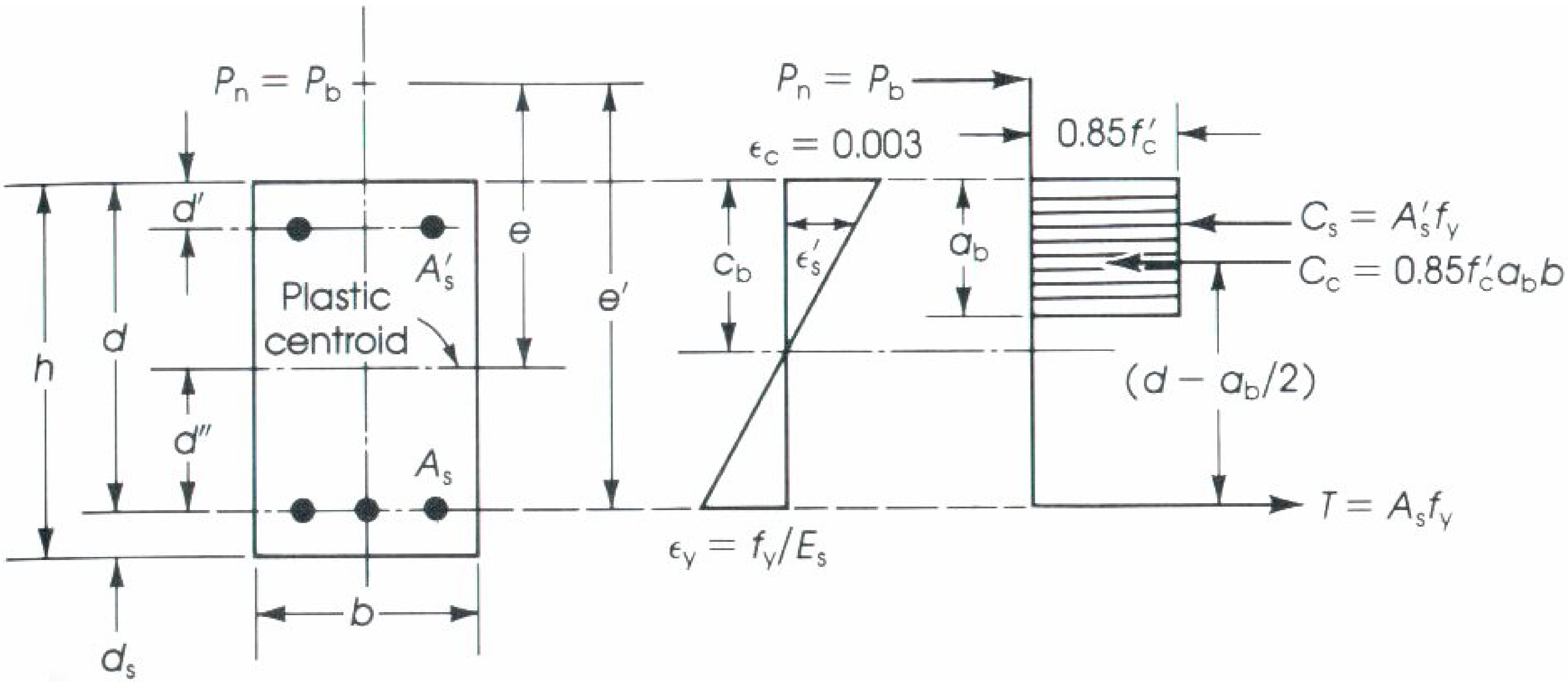
COMPARING CRASH FORCE AND WHEEL LOAD MOMENTS



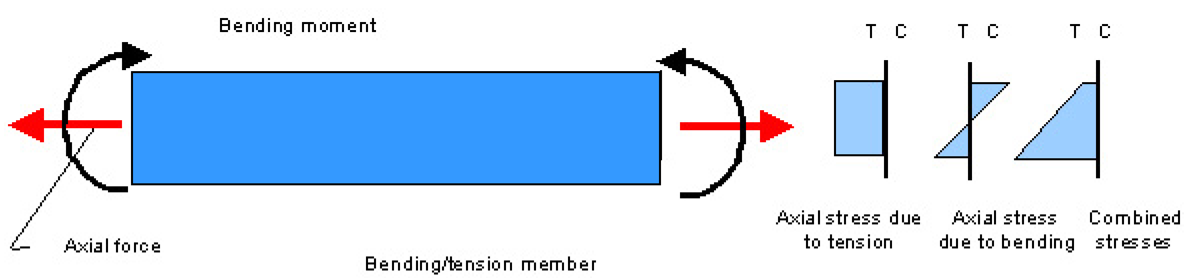


MOMENT-AXIAL TENSION INTERACTION

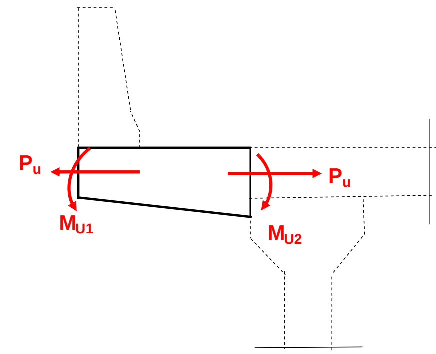
Computer Analysis
(Spreadsheet)

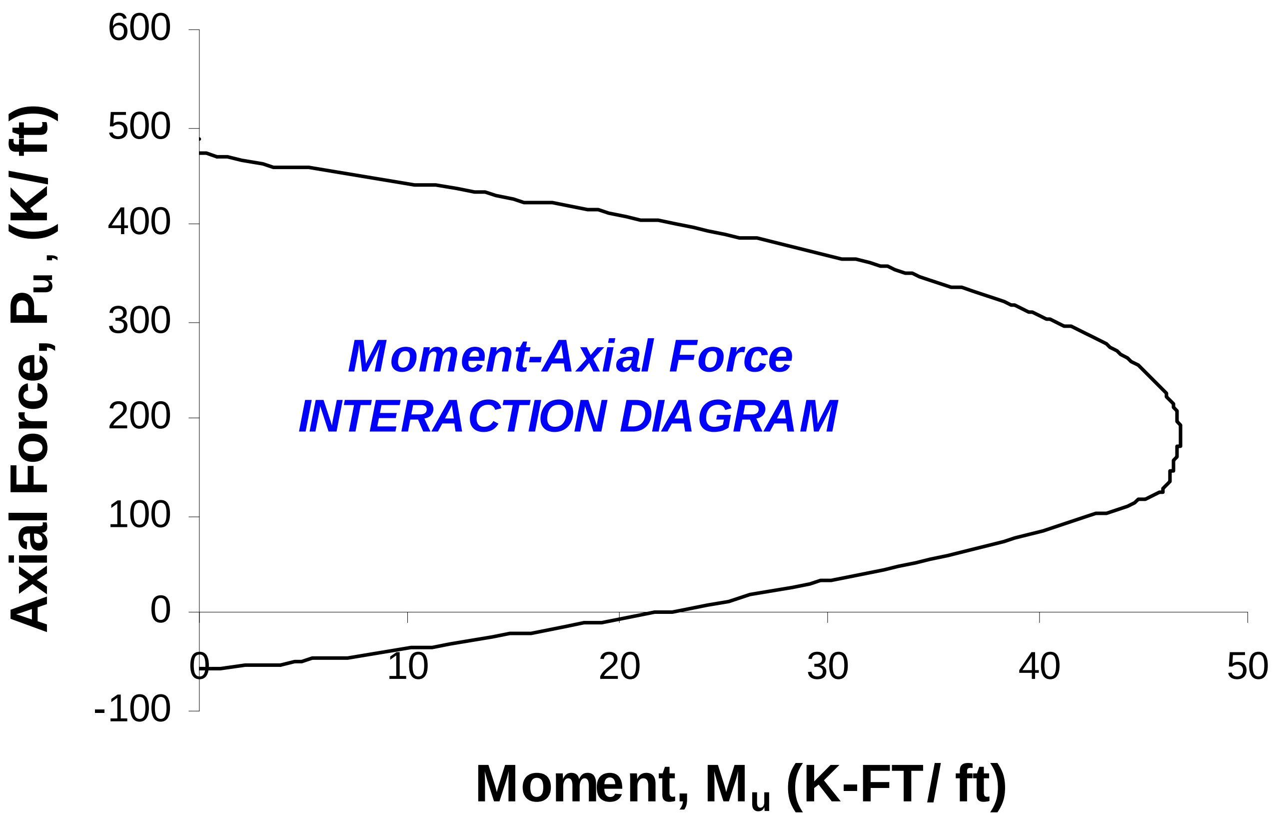


$P_n = P_b$
d'
A'_s
Plastic centroid
e
e'
d
h
d''
A_s
b
d_s
$\epsilon_c = 0.003$
c_b
ϵ'_s
$\epsilon_y = f_y/E_s$
a_b
$0.85f'_c$
$C_s = A'_s f_y$
$C_c = 0.85f'_c a_b b$
$(d - a_b/2)$
$T = A_s f_y$

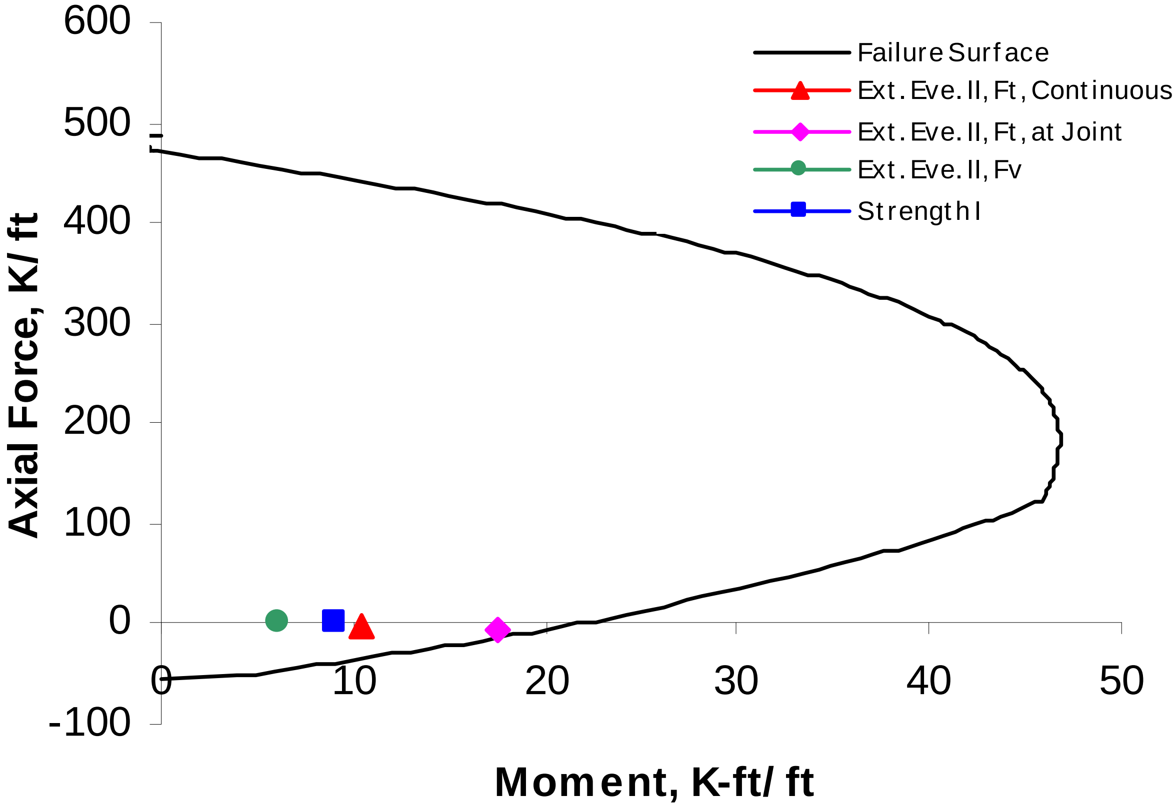


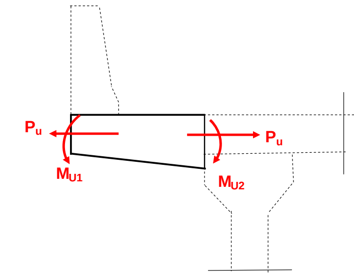
Bending moment
Axial force
Bending/tension member
T C
T C
T C
Axial stress due to tension
Axial stress due to bending
Combined stresses

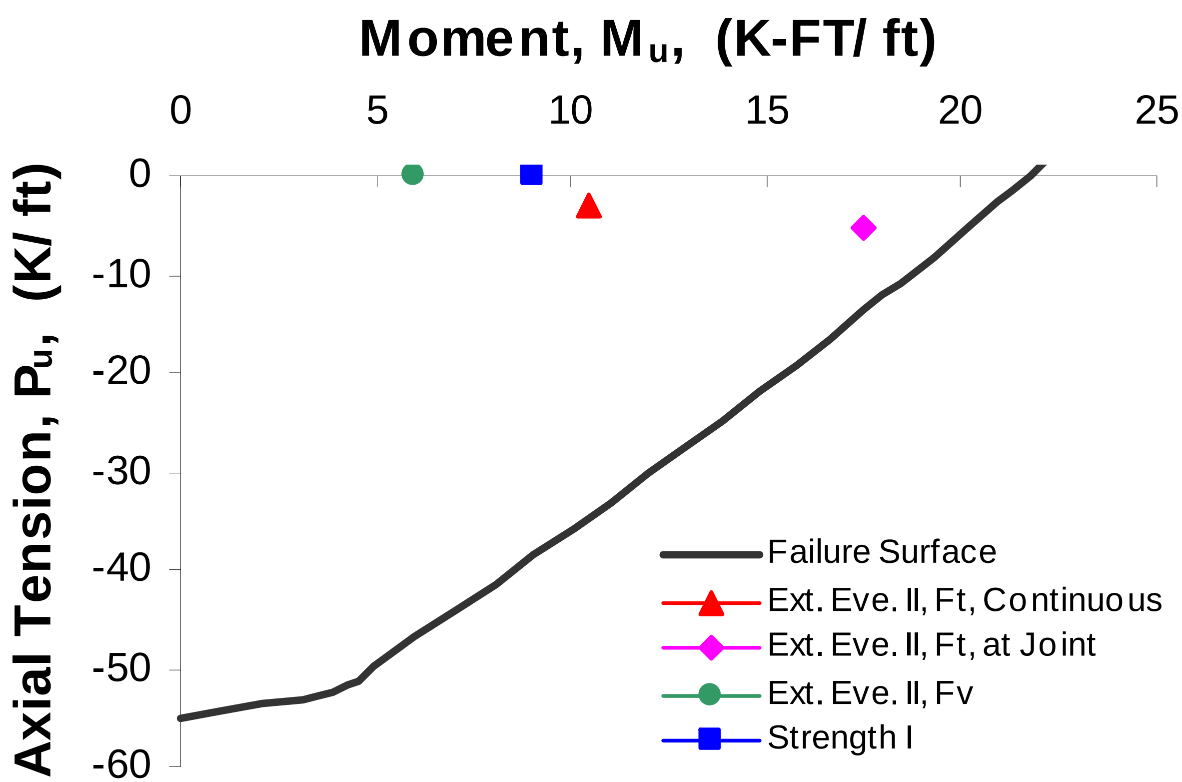

P u
P u
M U1
M U2

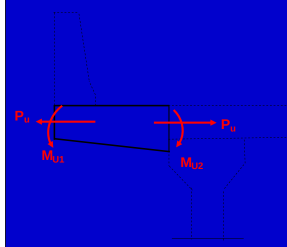

Moment-Axial Force
INTERACTION DIAGRAM
Axial Force, P u , (K/ ft)
Moment, M u (K-FT/ ft)
600
500
400
300
200
100
0
-100
0
10
20
30
40
50

Load Combinations are Plotted on Interaction Diagram







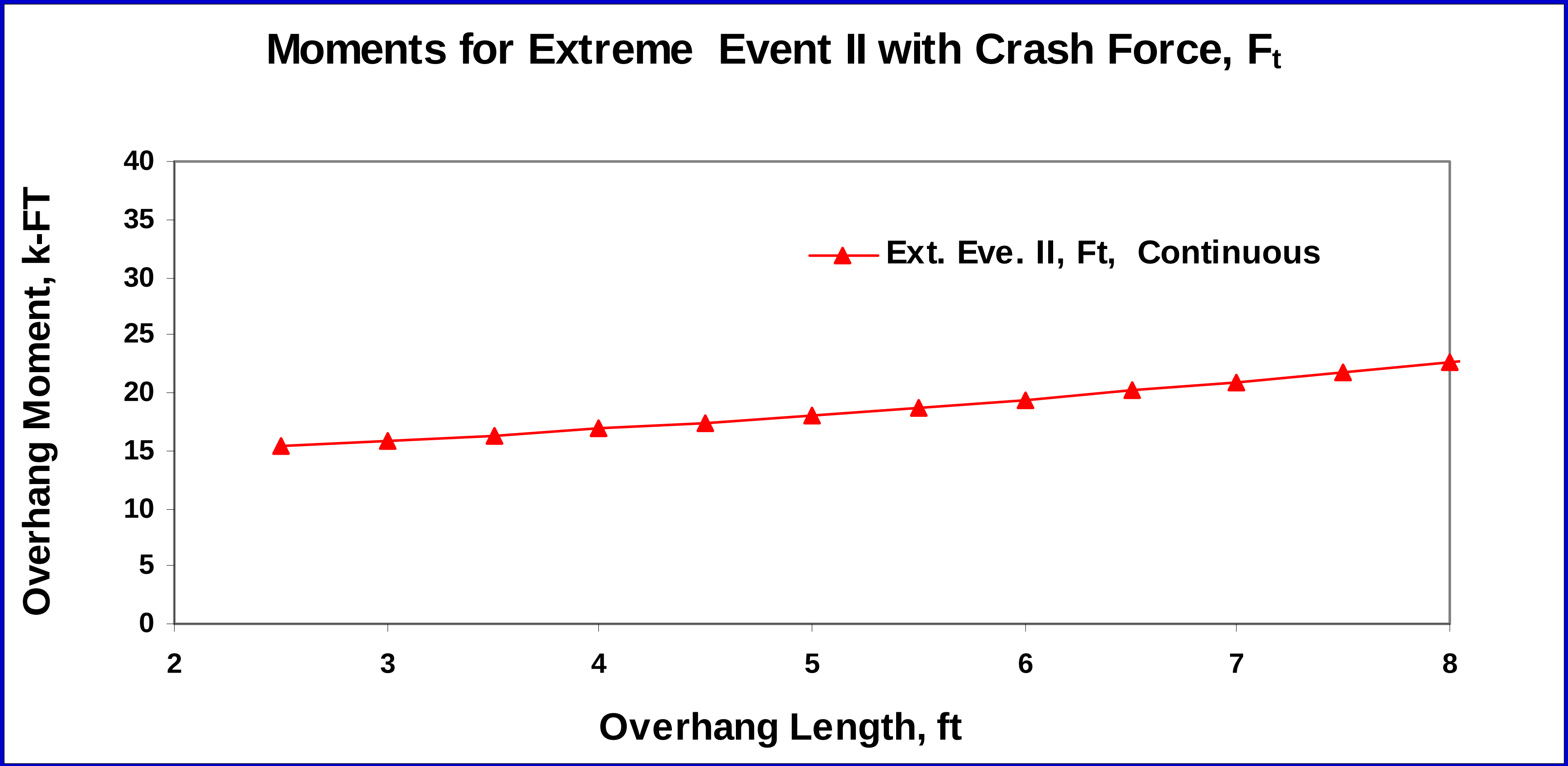


INTERACTION DIAGRAM
(Exploded Tensile Zone)

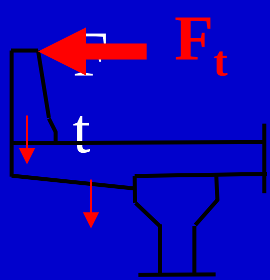
CRITICAL LOAD COMBINATION FOR OVERHANG

- **For All Practical Overhang Lengths, the Extreme Event HORIZONTAL CRASH LOADING is Critical**
- **ENDS OR JOINT Locations are More Critical**
- **Crash Internal Forces are Almost Constant Along the Overhang**
- **In Hunched Overhangs the MINIMUM THICKNESS CONTROLS**

Overhang Subject to:
Constant Moment and Axial Tension



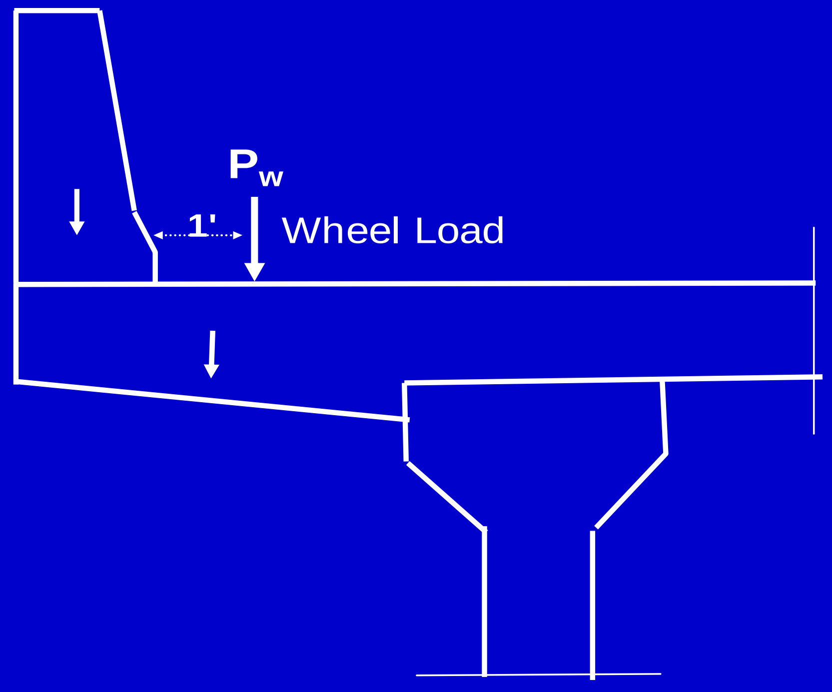
Needs Almost a Constant Thickness Hunch is not Optimizing the Design

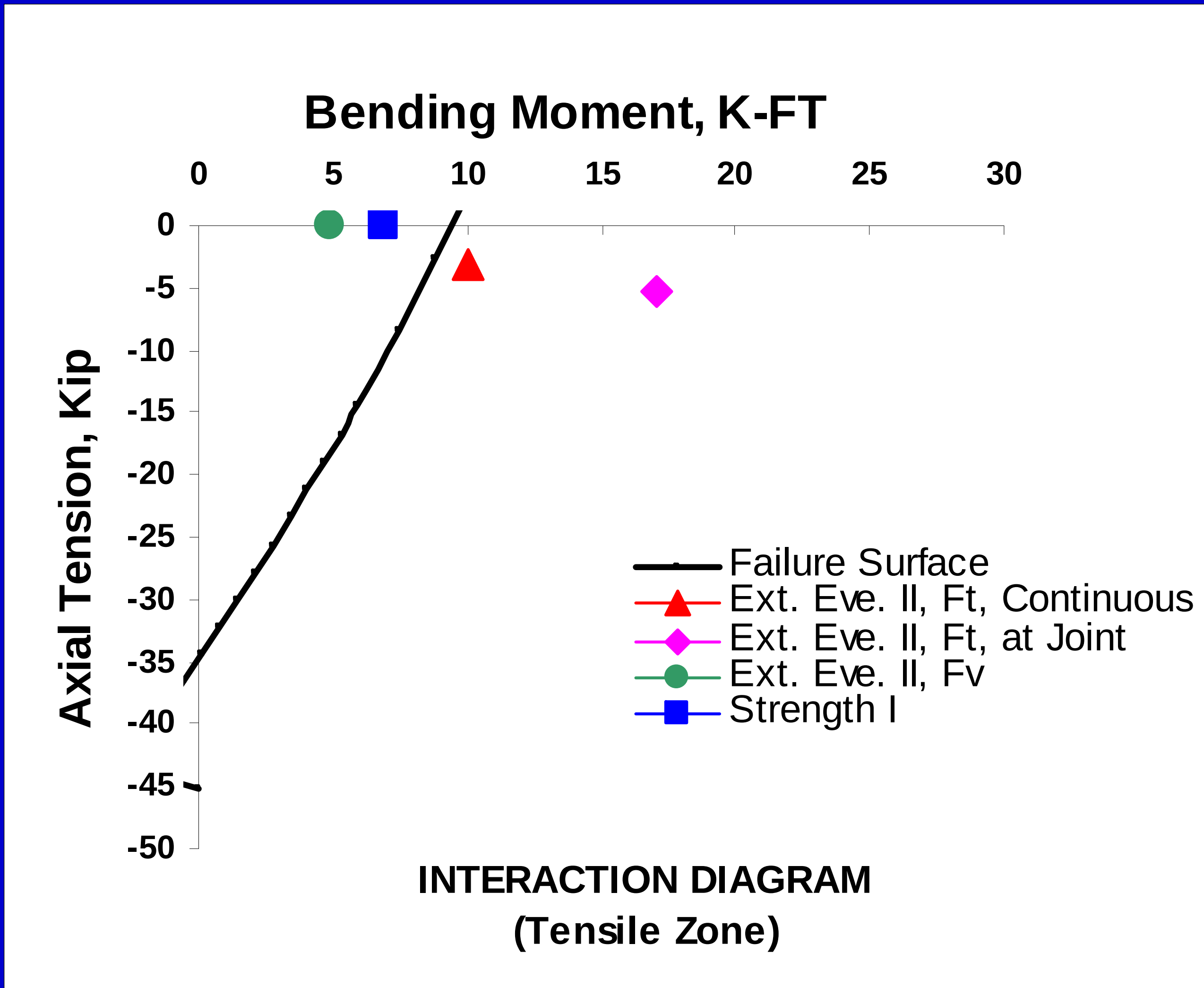


Standard (Traditional) Design Method:

- **Design the Overhang for the Wheel Load on the Overhang**

This Design <u>WILL NOT</u> Pass The Crash Forces



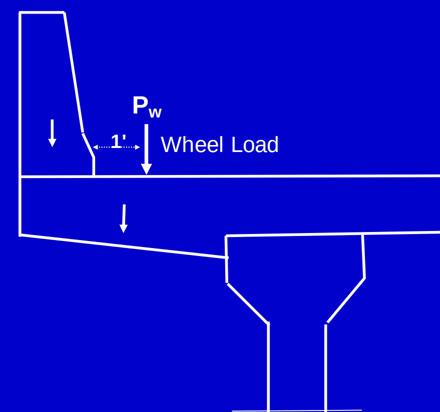


Overhang: 2.5 ft

Girder Spacing: 8 ft

Design Based on The Wheel Load:

Will NOT Pass the Crash Forces



Test Level: TL-4

Top Bars: #5@12

Bot. Bars: #5@7.6

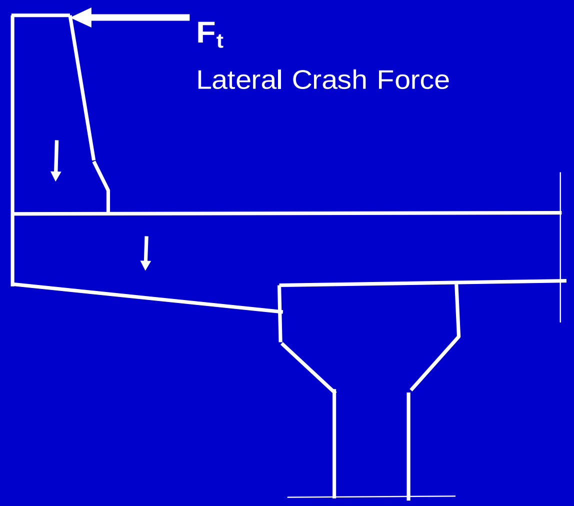
SUGGESTED DESIGN METHOD

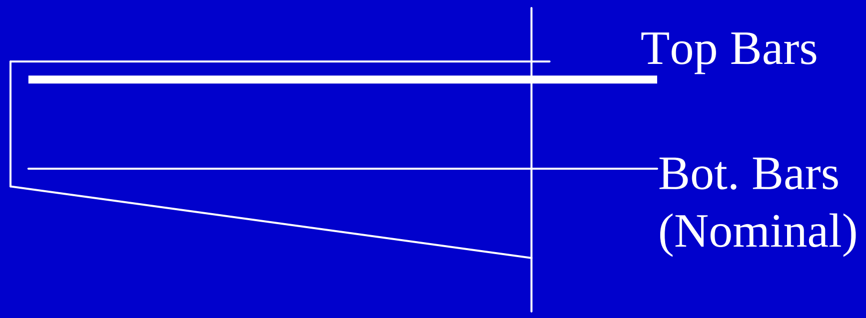
- **Design the Top Bars for Ext. Event Crushing Moment**

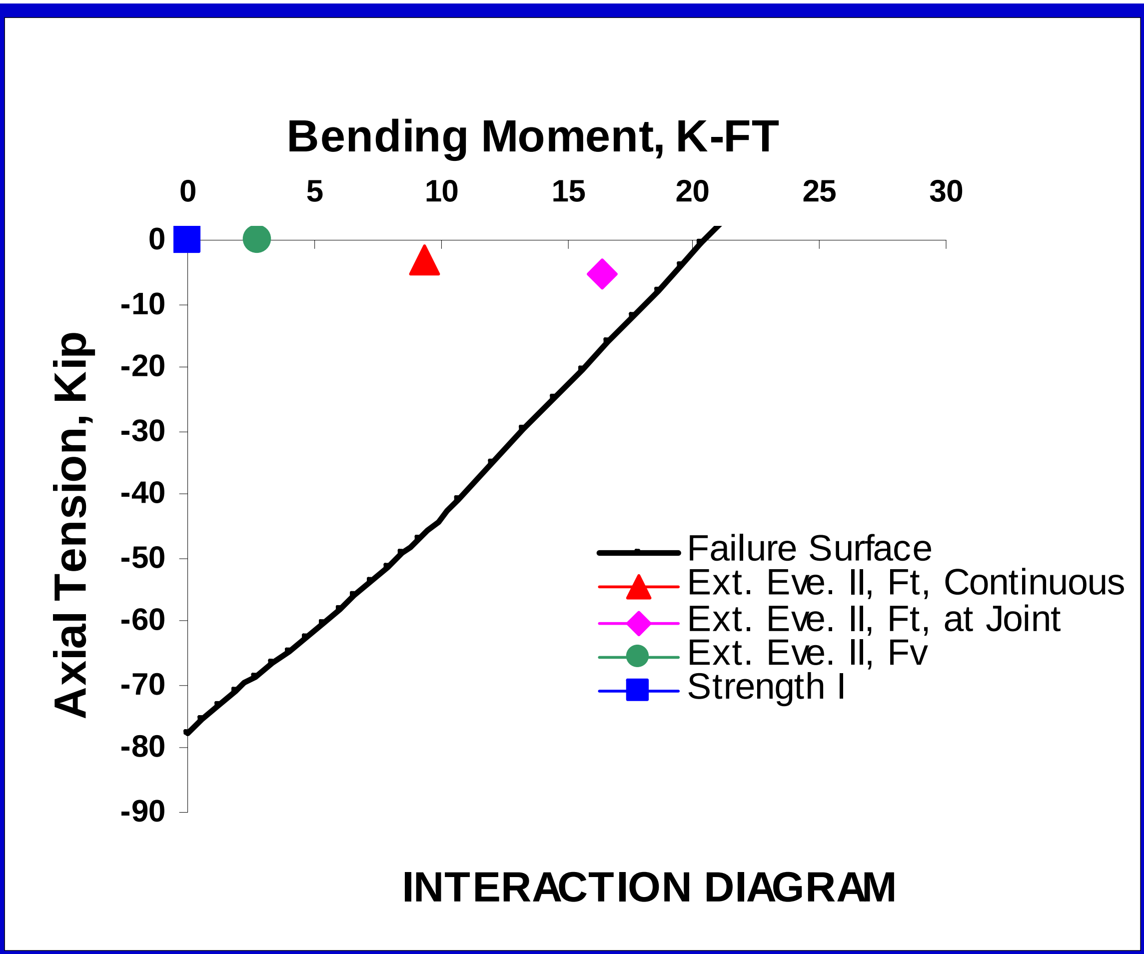
  (by ignoring the Axial Tension)

- **Provide Nominal Bottom Bars**

This Design Will Pass the LRFD Crash Forces for Most Practical Cases







Overhang: 2.5 ft

Girder Spacing: 8 ft

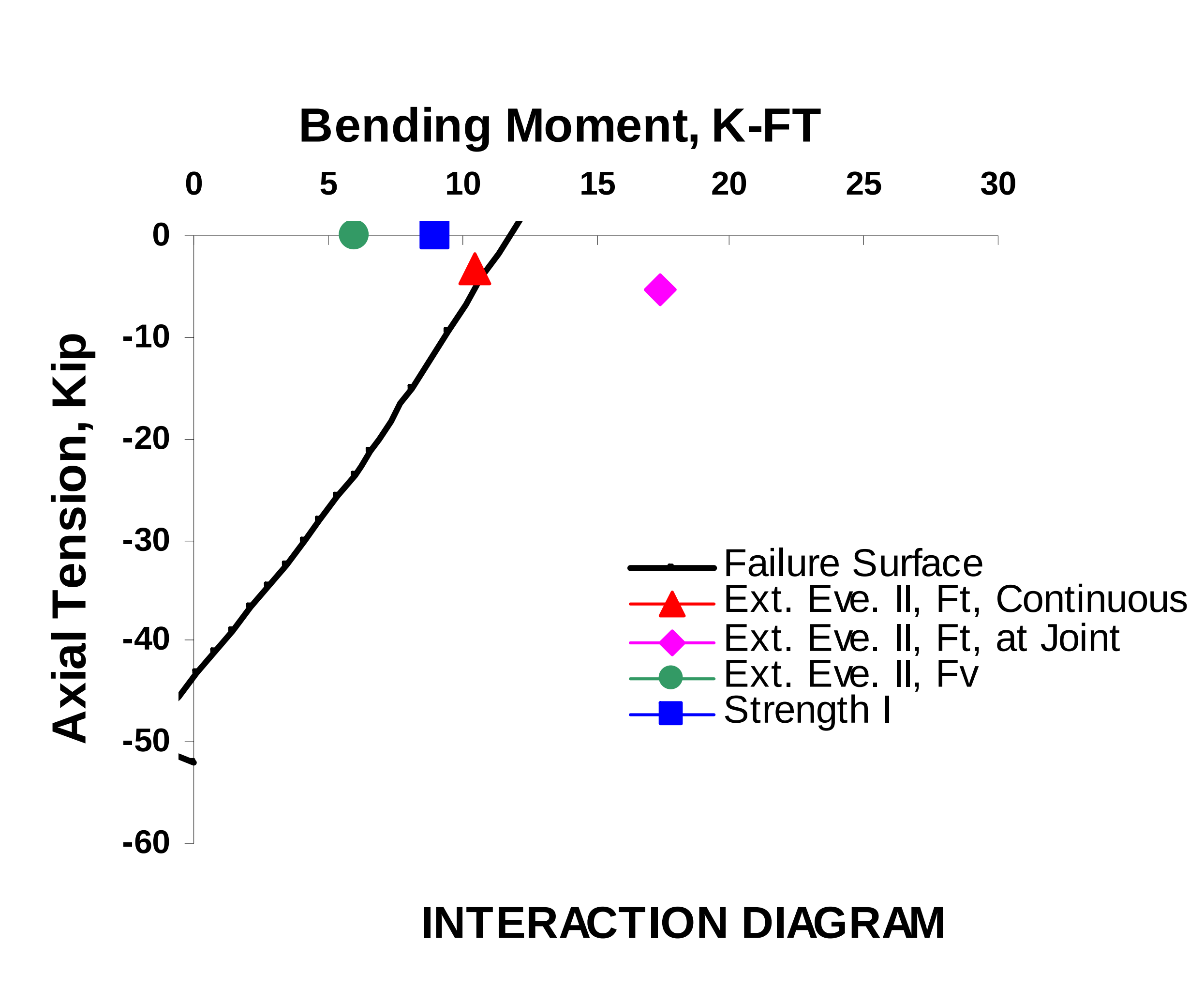
LRFD Design Based on: Crash Force at Joint

OK

Test Level: TL-4

Top Bars: #5@4.15

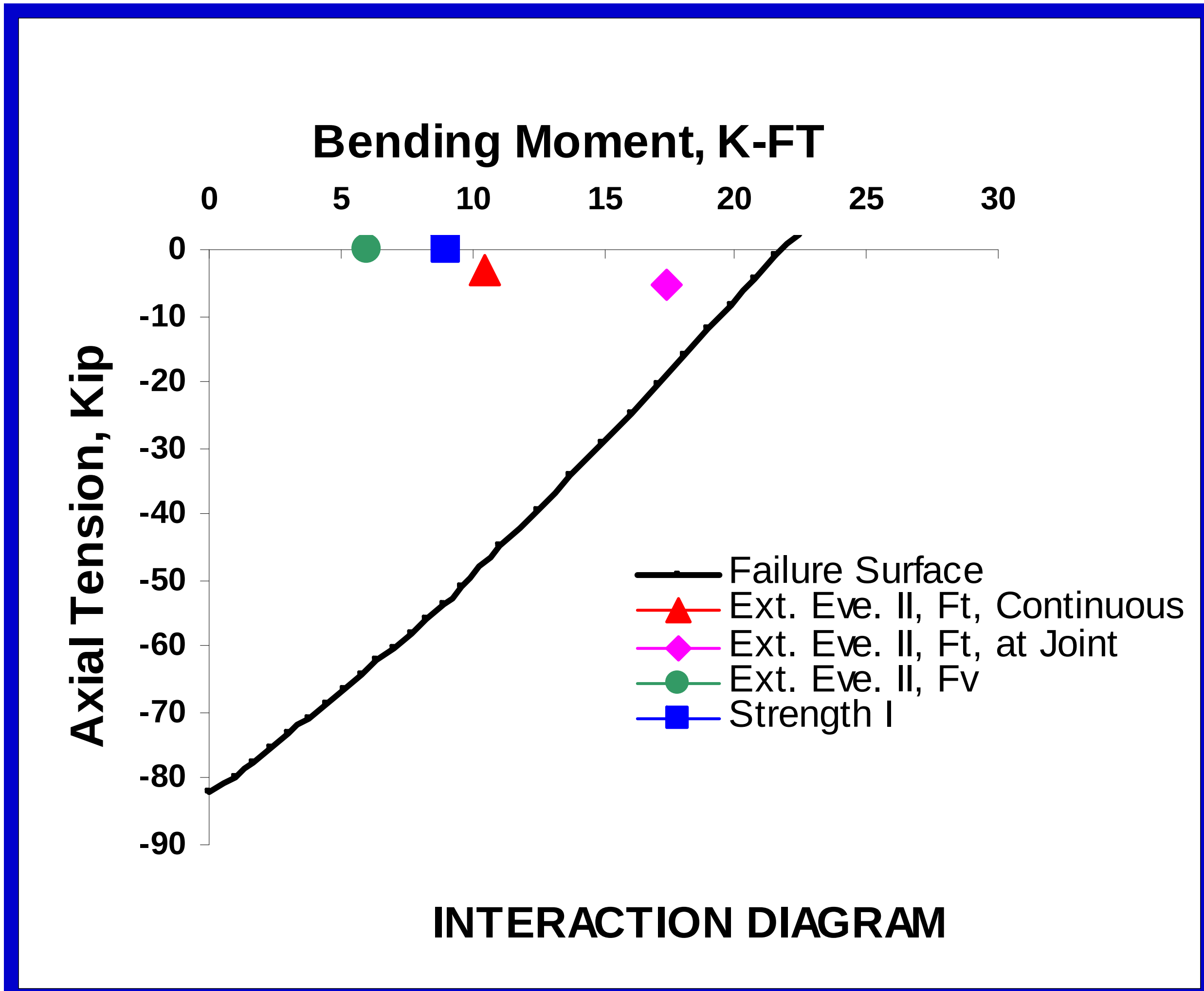
Bot. Bars: #5@9



Overhang: 4 ft
Girder Spacing: 8 ft

Standard Design Based on: Wheel Load
Not Good

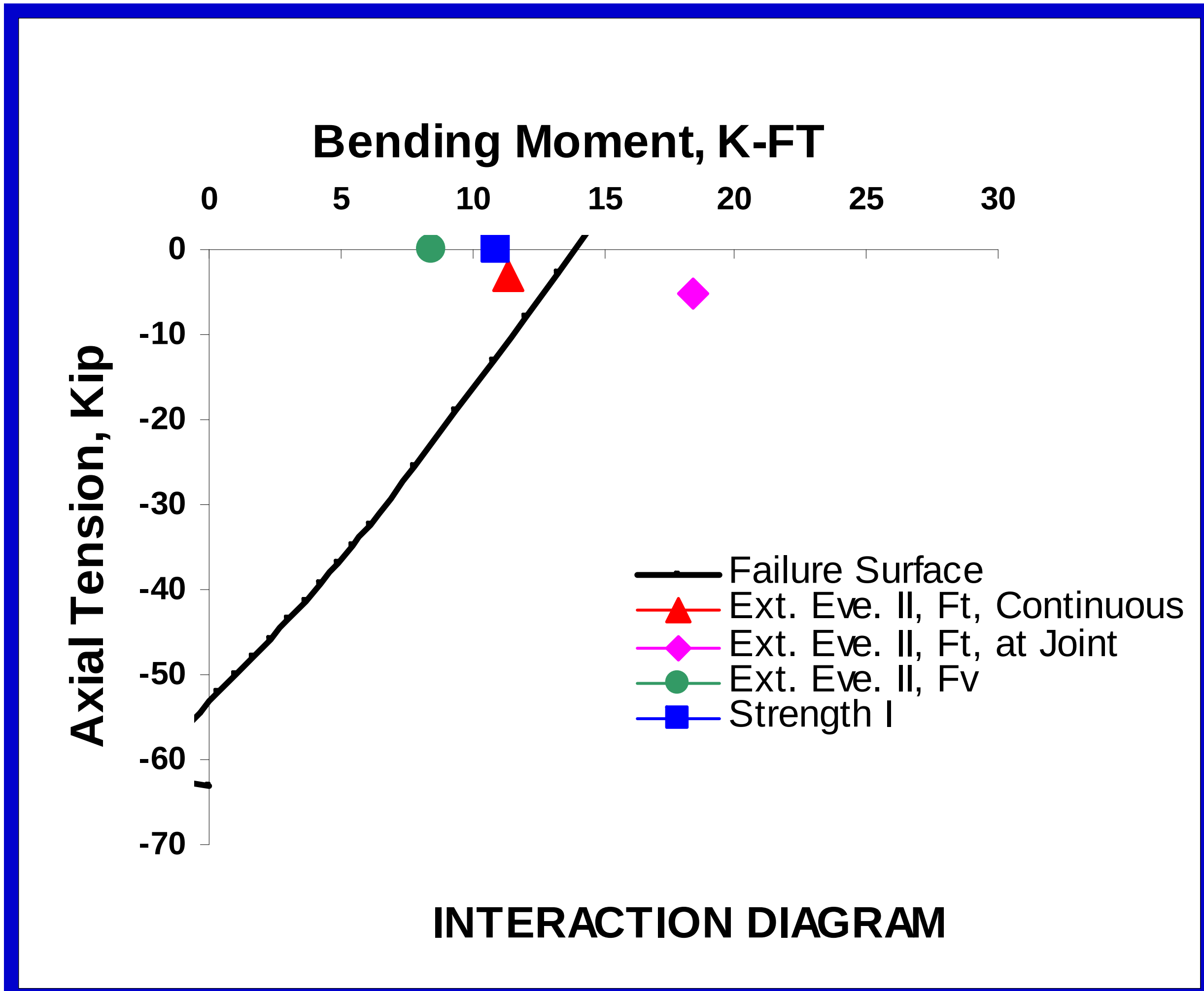
Test Level: TL-4
Top Bars: #5@8
Bot. Bars: #5@9.7



Overhang: 4 ft
Girder Spacing: 8 ft

LRFD Design
Based on:
Crash Force at Joint
OK

Test Level: TL-4
Top Bars: #5@3.84
Bot. Bars: #5@9



Overhang: 5 ft

Girder Spacing: 11 ft

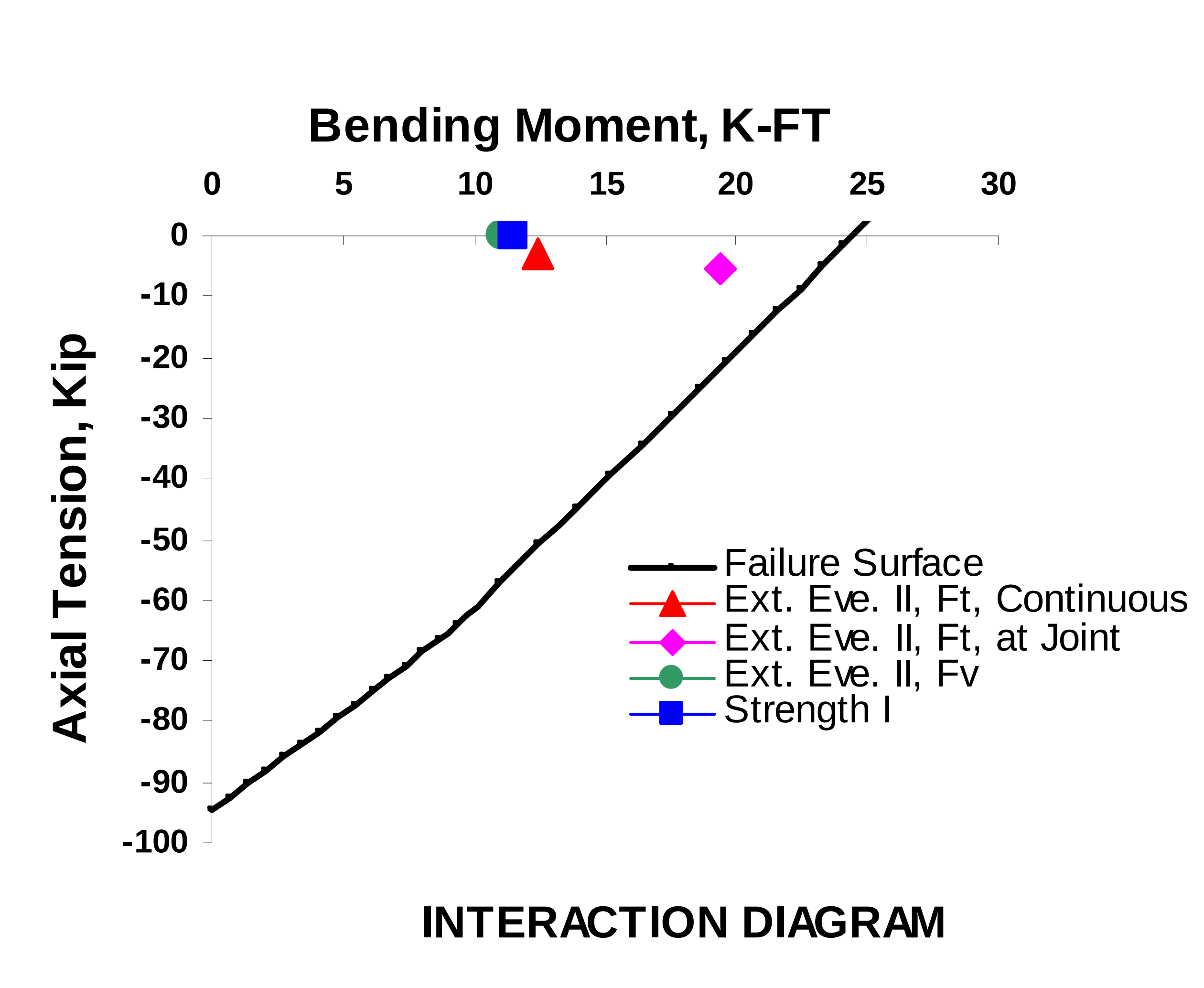
Standard Design Based on: Wheel Load

Not Good

Test Level: TL-4

Top Bars: 5@6.52

Bot. Bars: #5@7.6



Overhang: 5 ft

Girder Spacing: 11 ft

LRFD Design

Based on:

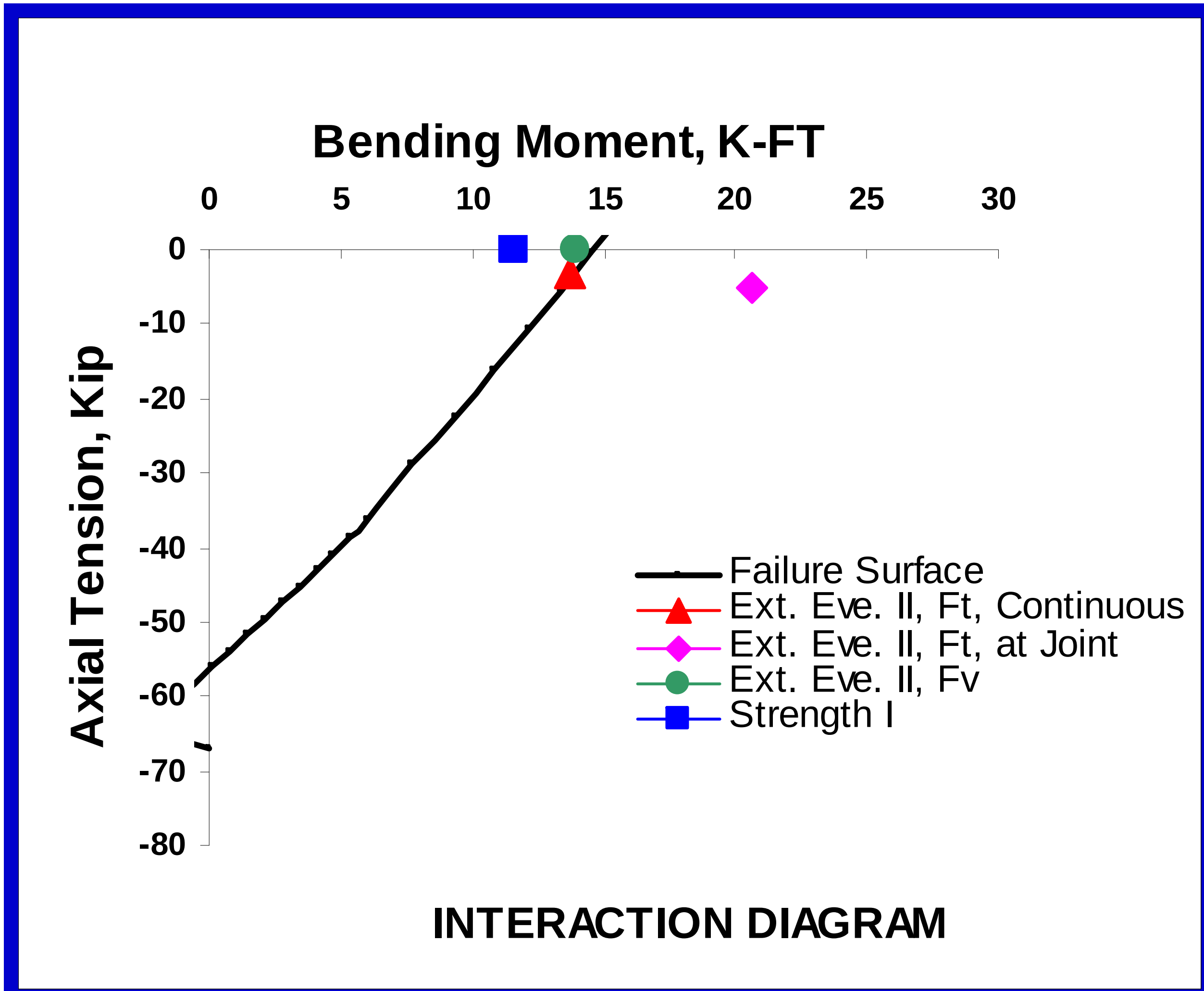
Crash Force at Joint

OK

Test Level: TL-4

Top Bars: #5@3.38

Bot. Bars: #5@7.6



Overhang: 7 ft

Girder Spacing: 13 ft

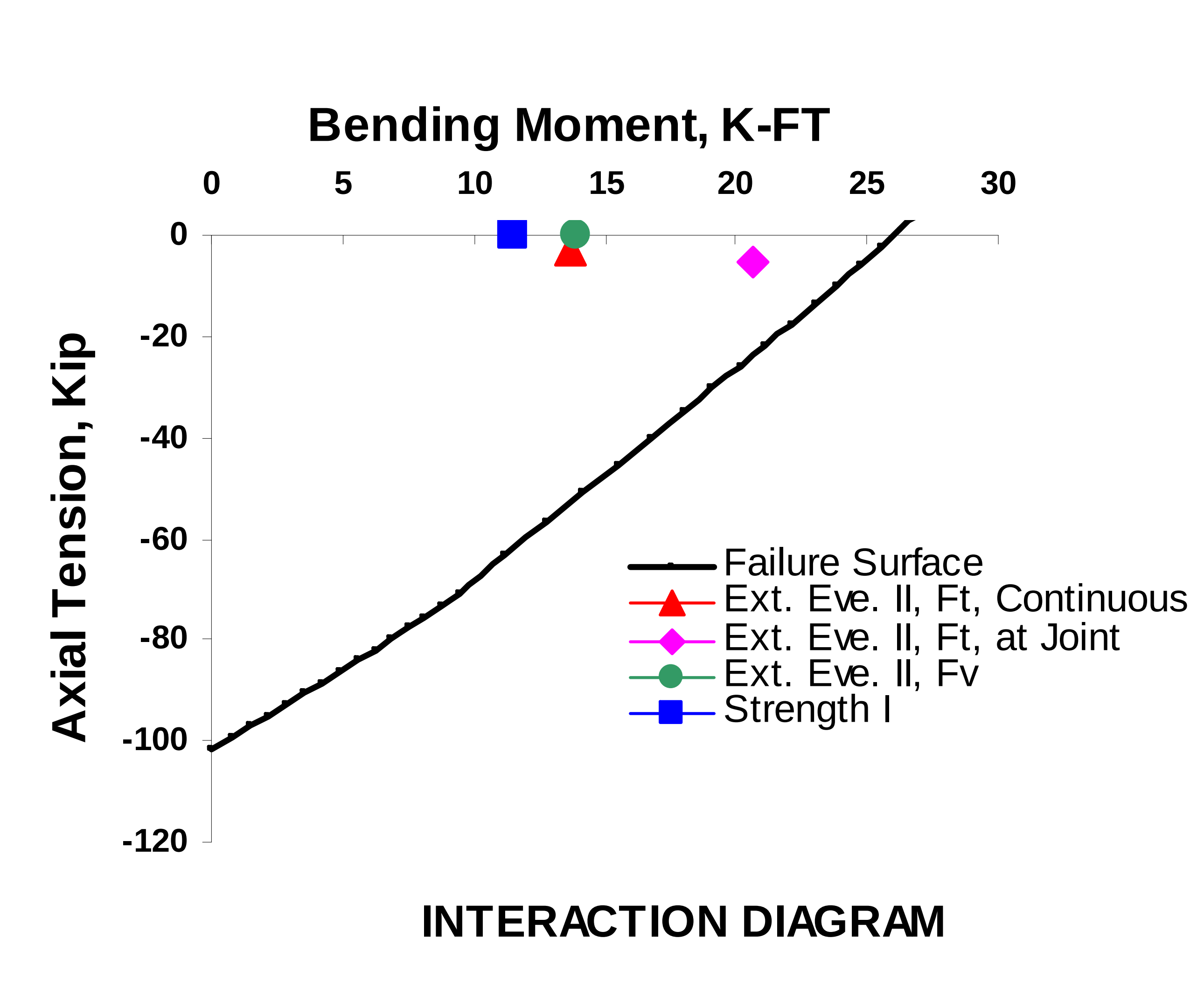
Standard Design Based on: Wheel Load

Not Good

Test Level: TL-4

Top Bars: #5@6.14

Bot. Bars: #5@7.14



Overhang: 7 ft

Girder Spacing: 13 ft

LRFD Design

Based on:

Crash Force at Joint

OK

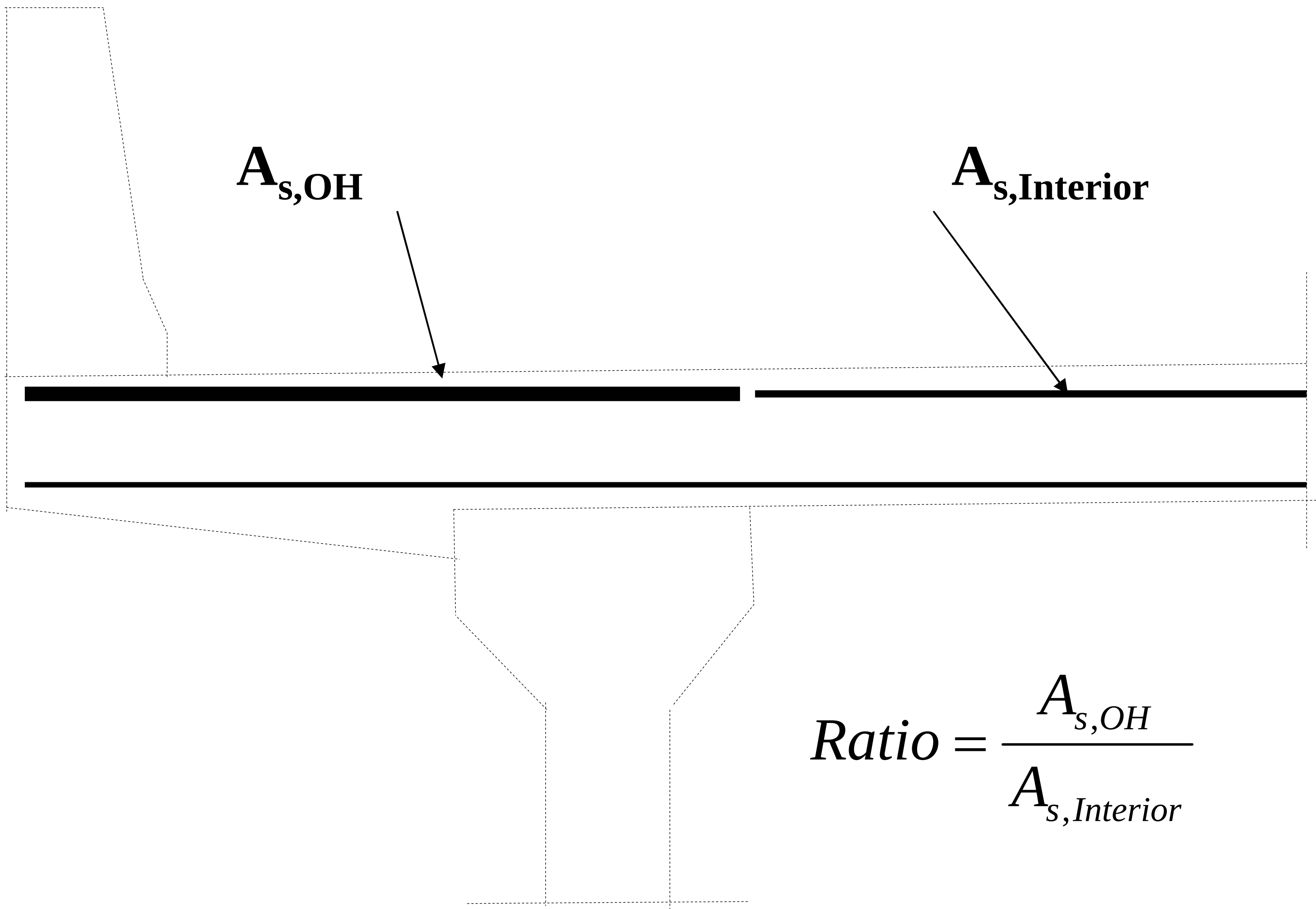
Test Level: TL-4

Top Bars: #5@3.13

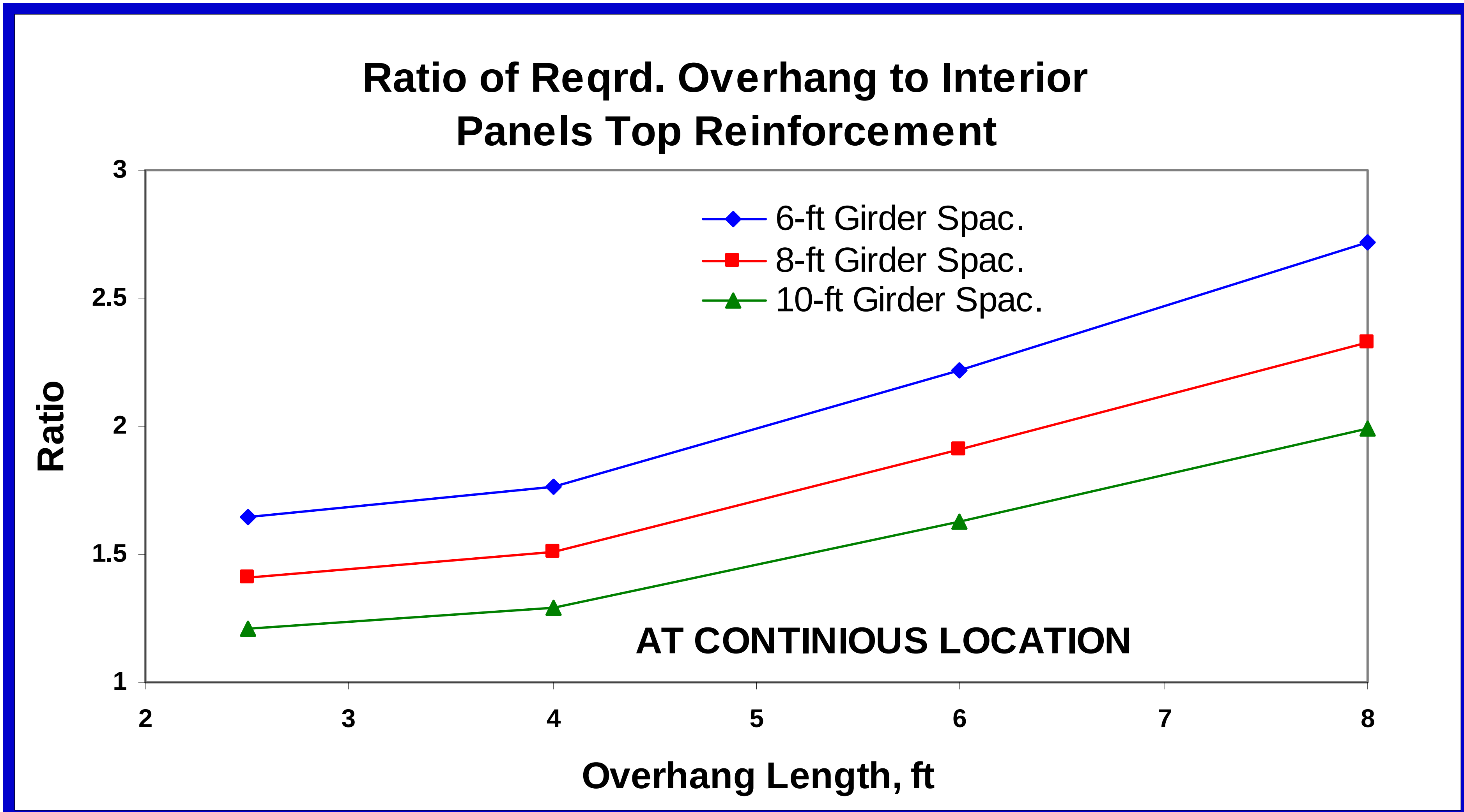
Bot. Bars: #5@7.14

COMPARISON OF REQUIRED OVERHANG TOP BARS AND INTERIOR DECK PANEL TOP BARS

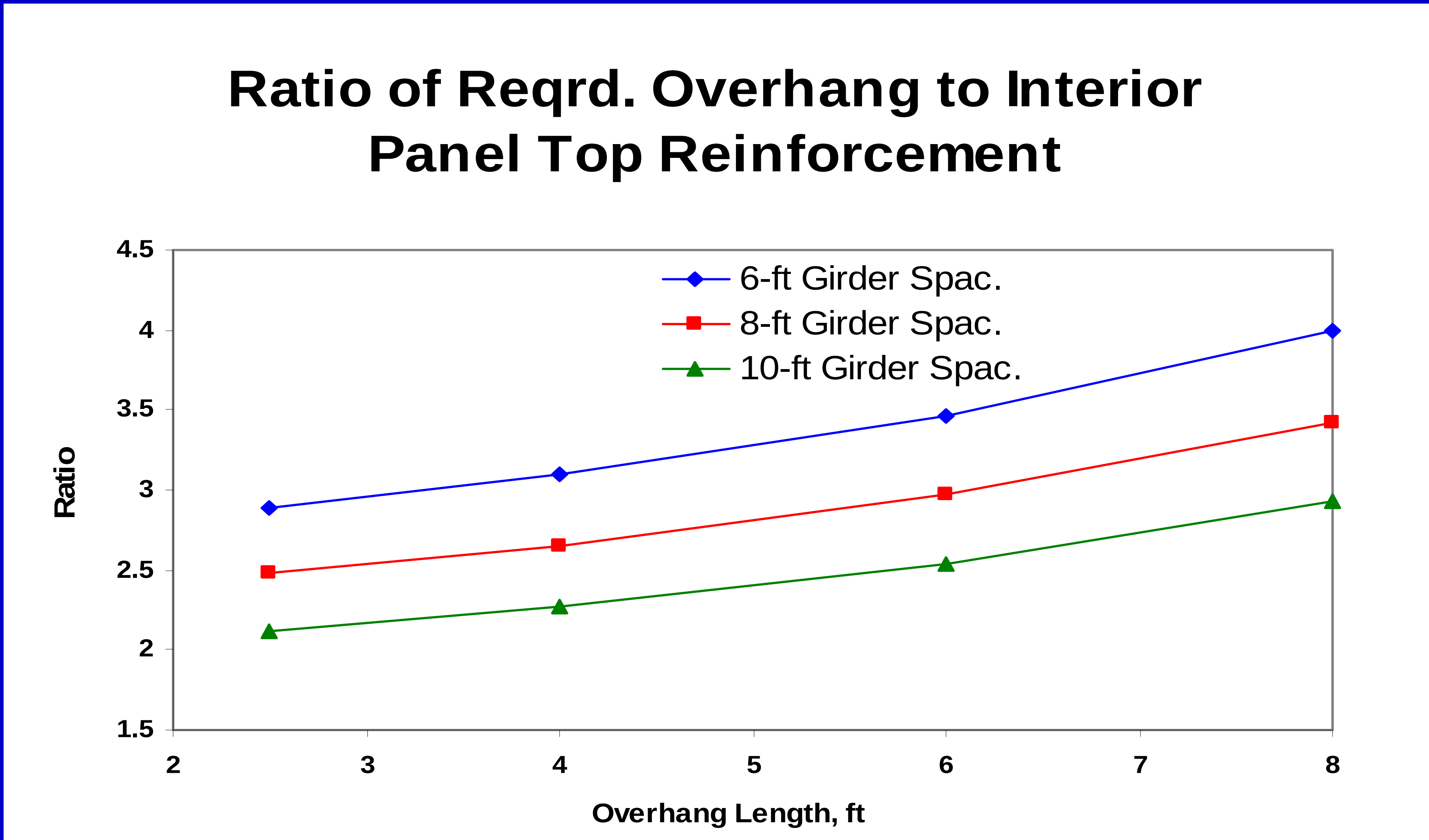
How Much Overhang Top Reinforcement Should We expect ?



$$Ratio = \frac{A_{s,OH}}{A_{s,Interior}}$$



Ratio of Reqrd. Overhang to Interior Panels Top Reinforcement
6-ft Girder Spac.
8-ft Girder Spac.
10-ft Girder Spac.
AT CONTINIOUS LOCATION
Ratio
Overhang Length, ft
3
2.5
2
1.5
1
2
3
4
5
6
7
8


Ratio of Reqrd. Overhang to Interior Panel Top Reinforcement
6-ft Girder Spac.
8-ft Girder Spac.
10-ft Girder Spac.
Ratio
4.5
4
3.5
3
2.5
2
1.5
2
3
4
5
6
7
8
Overhang Length, ft

DESIGN SIMPLIFICATION:

1. **Find the Max. Moment for Horizontal Crash Extreme Event**
2. **Design the Top Bars for Overhang Based on This Moment Only**

(Use Minimum Thickness and Consider no Axial Force)

1. **Provide the Nominal Bottom Bars**
2. **It was Shown That This Design Will Satisfy Combined Action of Moment-Axial Force For All Practical Cases**

CONCLUSIONS

- Standard Wheel Load Application **WILL NOT** Govern the LRFD Design for Overhangs
- Extreme Event Crash (Horizontal) Forces **MUST BE** Considered To Satisfy LRFD for All Overhang Lengths

CONCLUSIONS

- **Almost Constant Moment and Axial Forces Acting Along Overhang**
- **This Means a Variable Thickness (Hunch) Can not Optimizing the Design**
- **We Should Expect the Overhang Top Bars to be *ABOUT 1.5 to 2.5 TIMES* the Top Bars of The Interior Panel Top Reinforcement**