Bridging the Gap:
Answering Questions Through Research

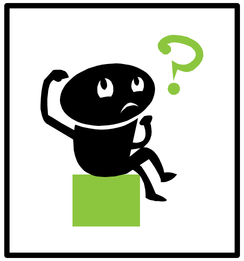
Catherine Hovell, PhD

October 1, 2012

…one direction a UVa degree can take you …

T·Y·LIN INTERNATIONAL
engineers | planners | scientists

Flow of Test Program

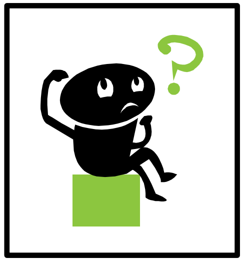


Can we ______________________________?

What about ___________________________?

What happens if _______________________?

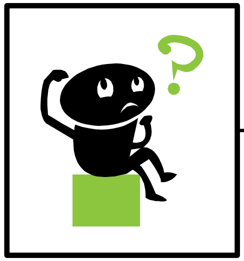
Flow of Test Program

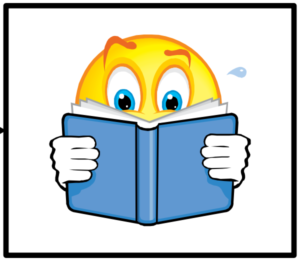


Can we optimize the end-region of Texas U-Beams?

- ease construction
- maintain structural performance

Flow of Test Program

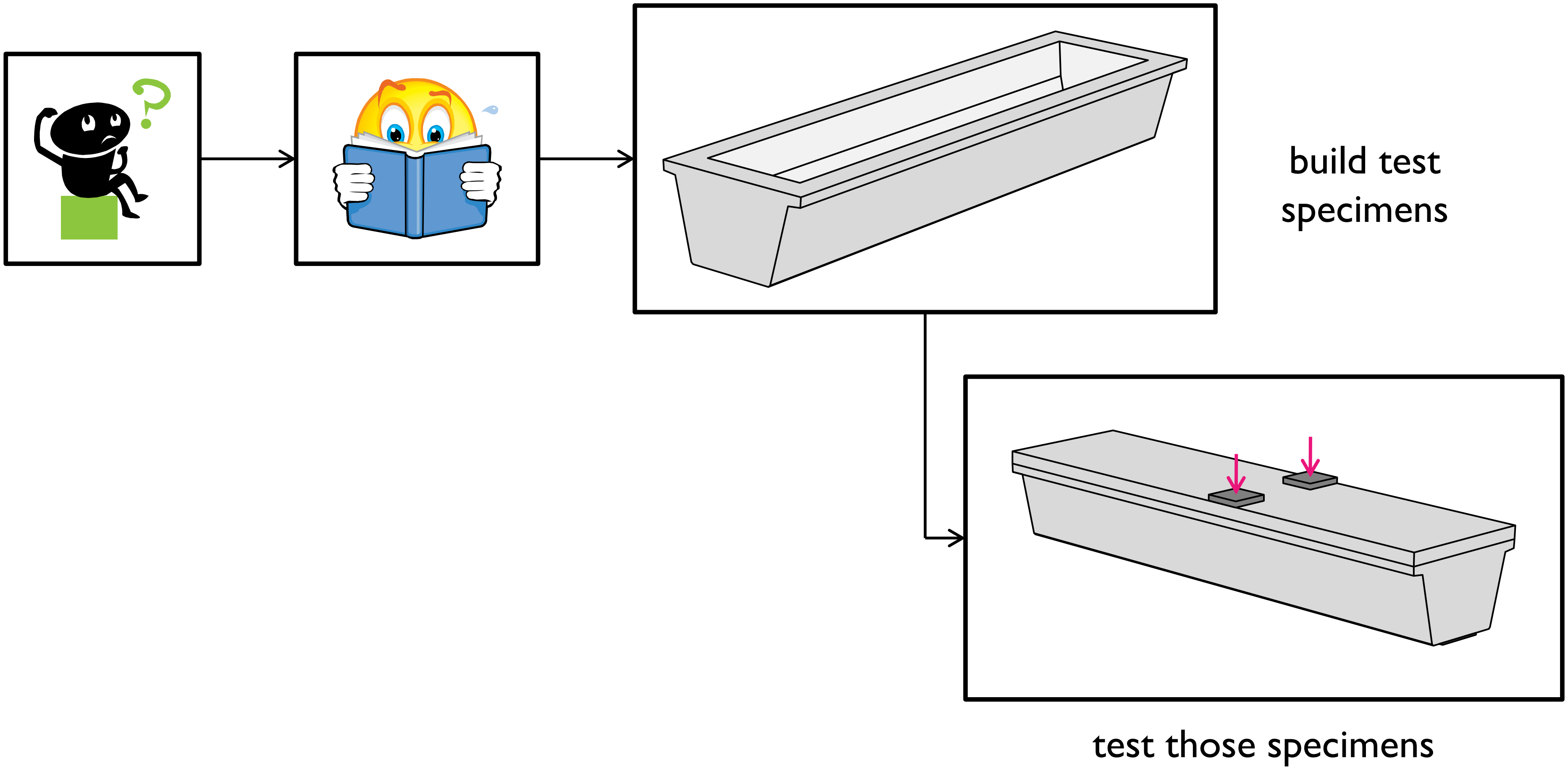




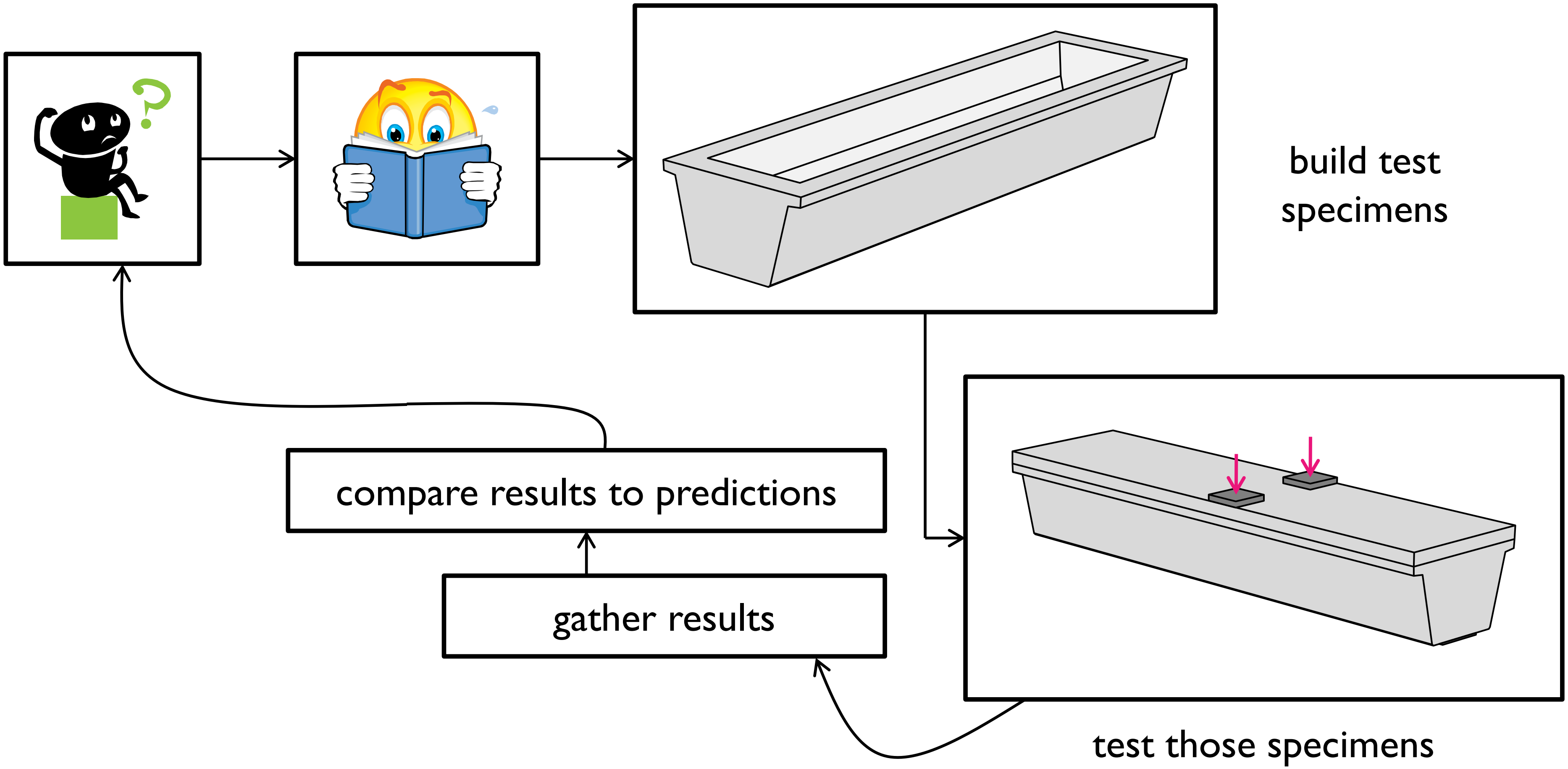
Literature Review:

- What previous testing has been done?
- What is the current performance of the structure?

Flow of Test Program



Flow of Test Program



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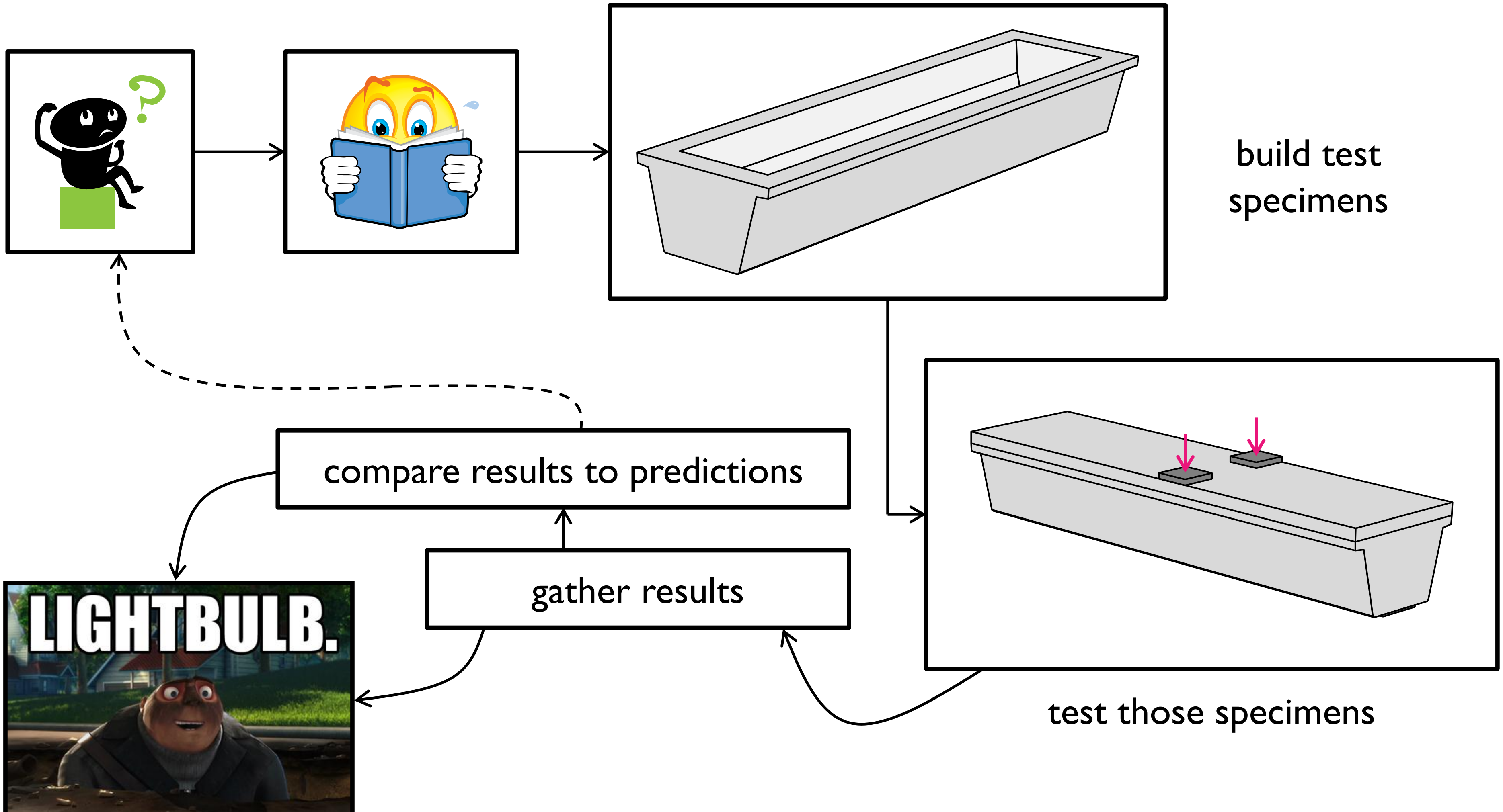
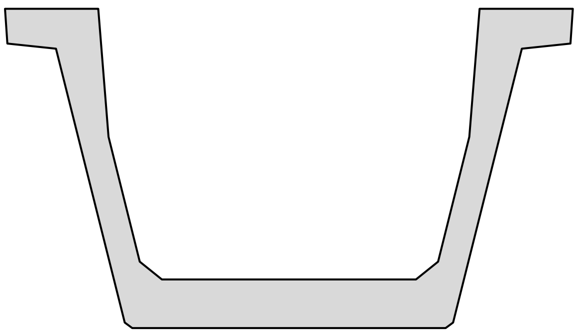
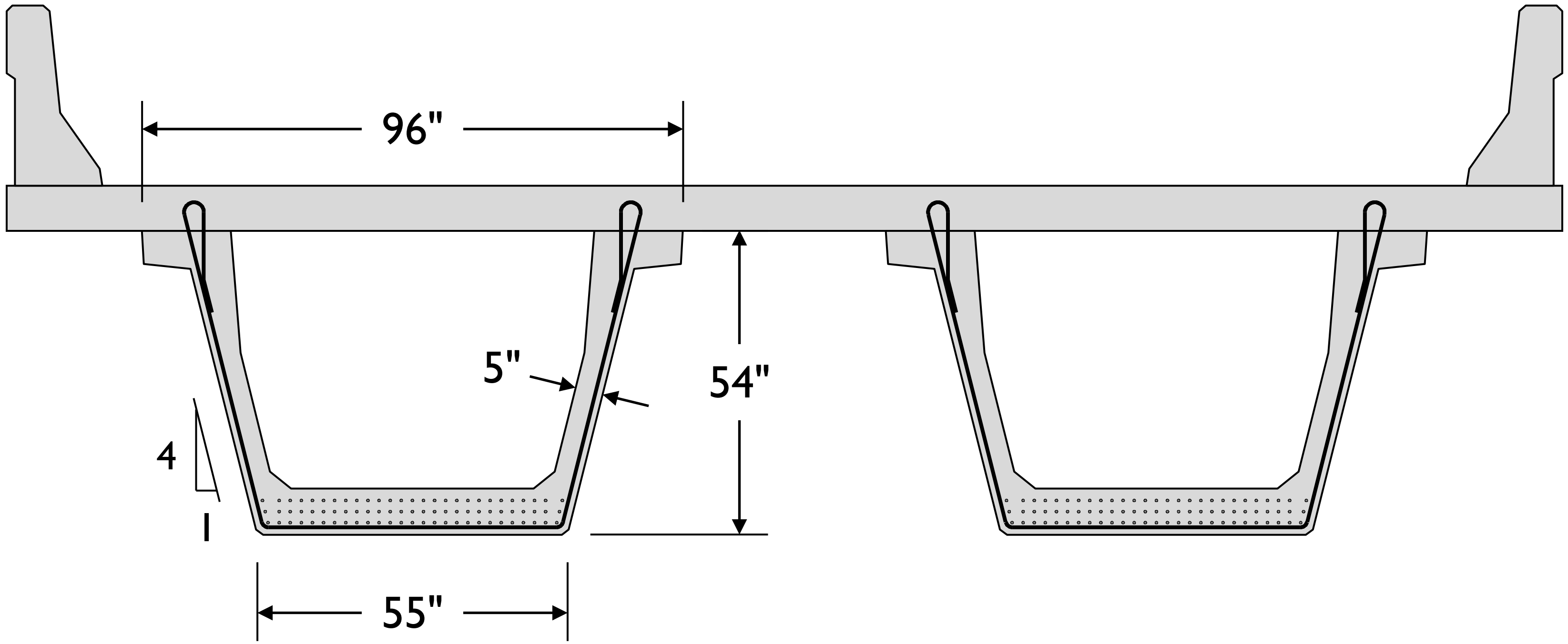


Introduction to the Texas U-Beam

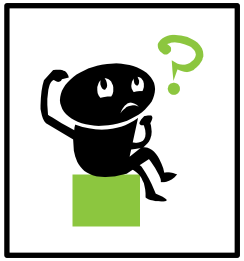
- Designed in the 1990s as an "aesthetically pleasing" alternative for use in highly visible interchanges



Introduction to the Texas U-Beam



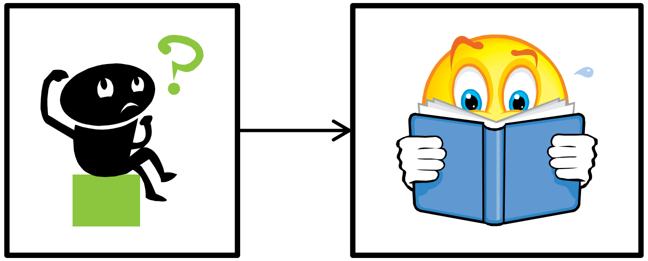
Flow of Test Program



Can we optimize the end-region of Texas U-Beams?

- ease construction
- maintain structural performance

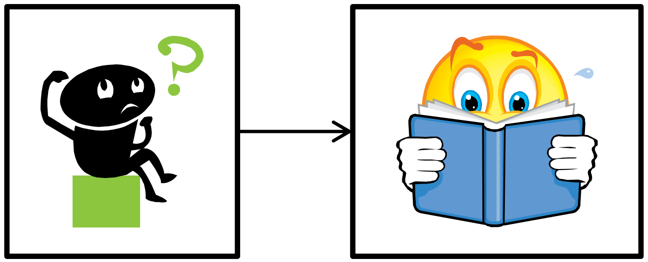
Flow of Test Program



Literature Review:

- What previous testing has been done?

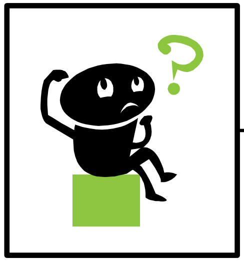
Flow of Test Program

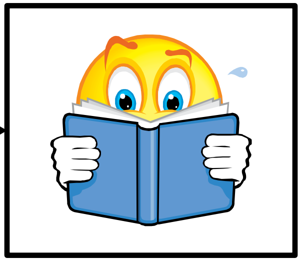


Literature Review:

- What previous testing has been done?
  - …on U-Beams
  - …under shear load

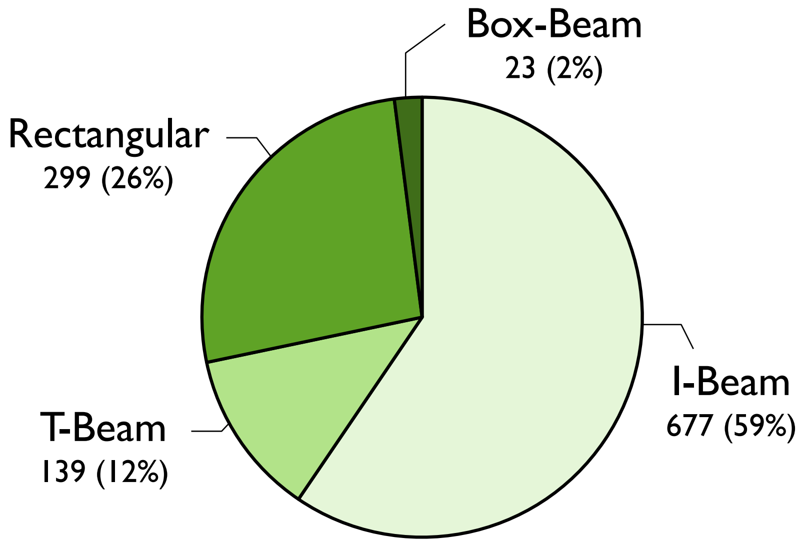
Flow of Test Program





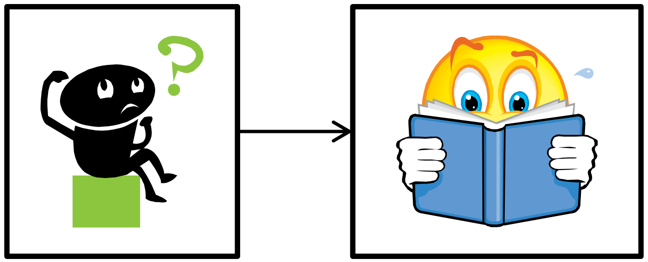
Literature Review:

- What previous testing has been done?
  - …on U-Beams
  - …under shear load



[data from UTPCSDB Filtered Database, N = 1138]

Flow of Test Program



Literature Review:

- What previous testing has been done?
  - …on U-Beams - not much
  - …under shear load - no tests of U-Beams
- What is the current performance of the structure?

Expectations:
Shear Strength

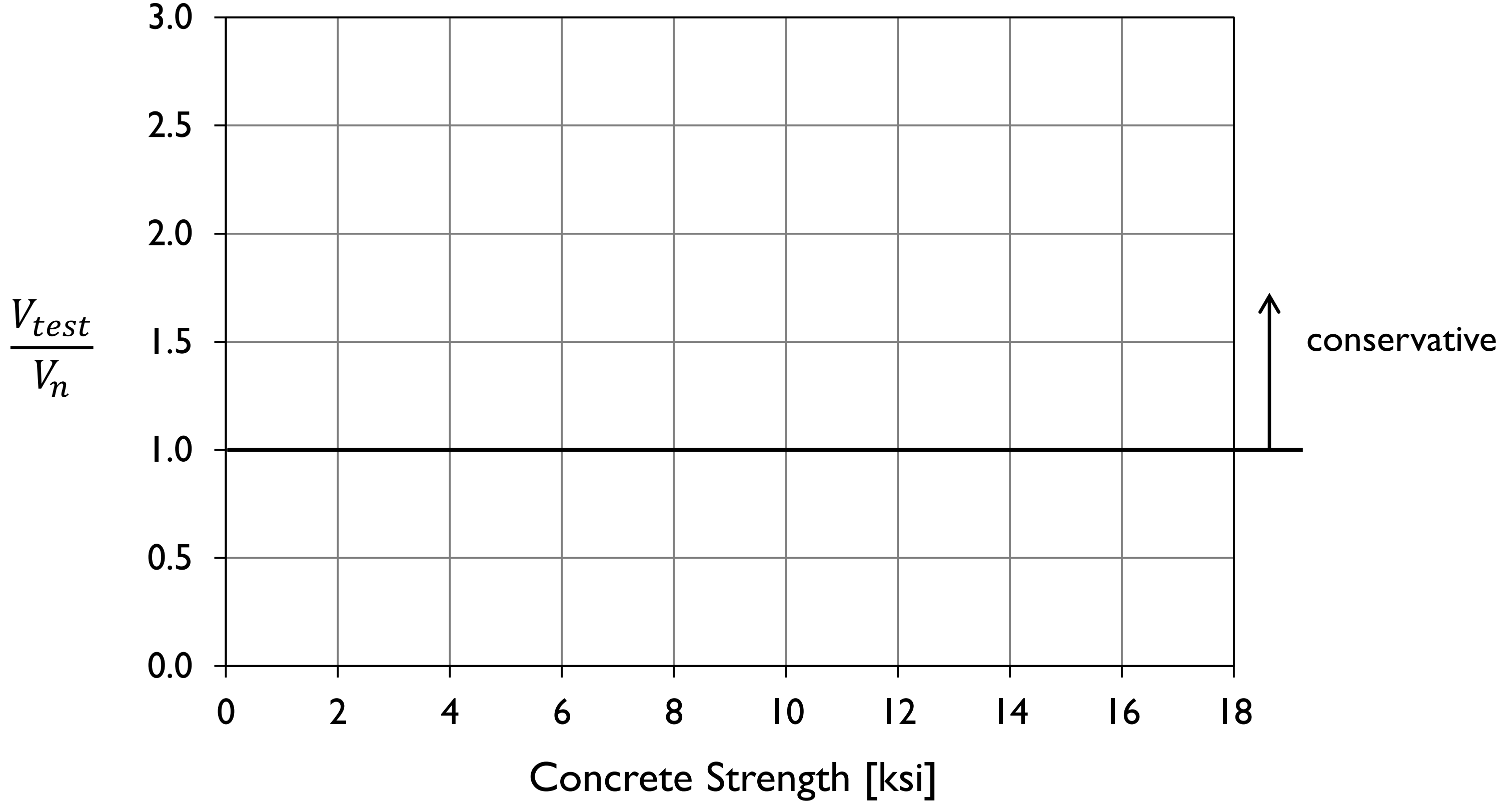
University of Texas Prestressed Concrete Shear Database (2011 Edition) [UTPCSDB-2011]

» 99 references from 1954-2010

» shear studies from US, Europe, Japan

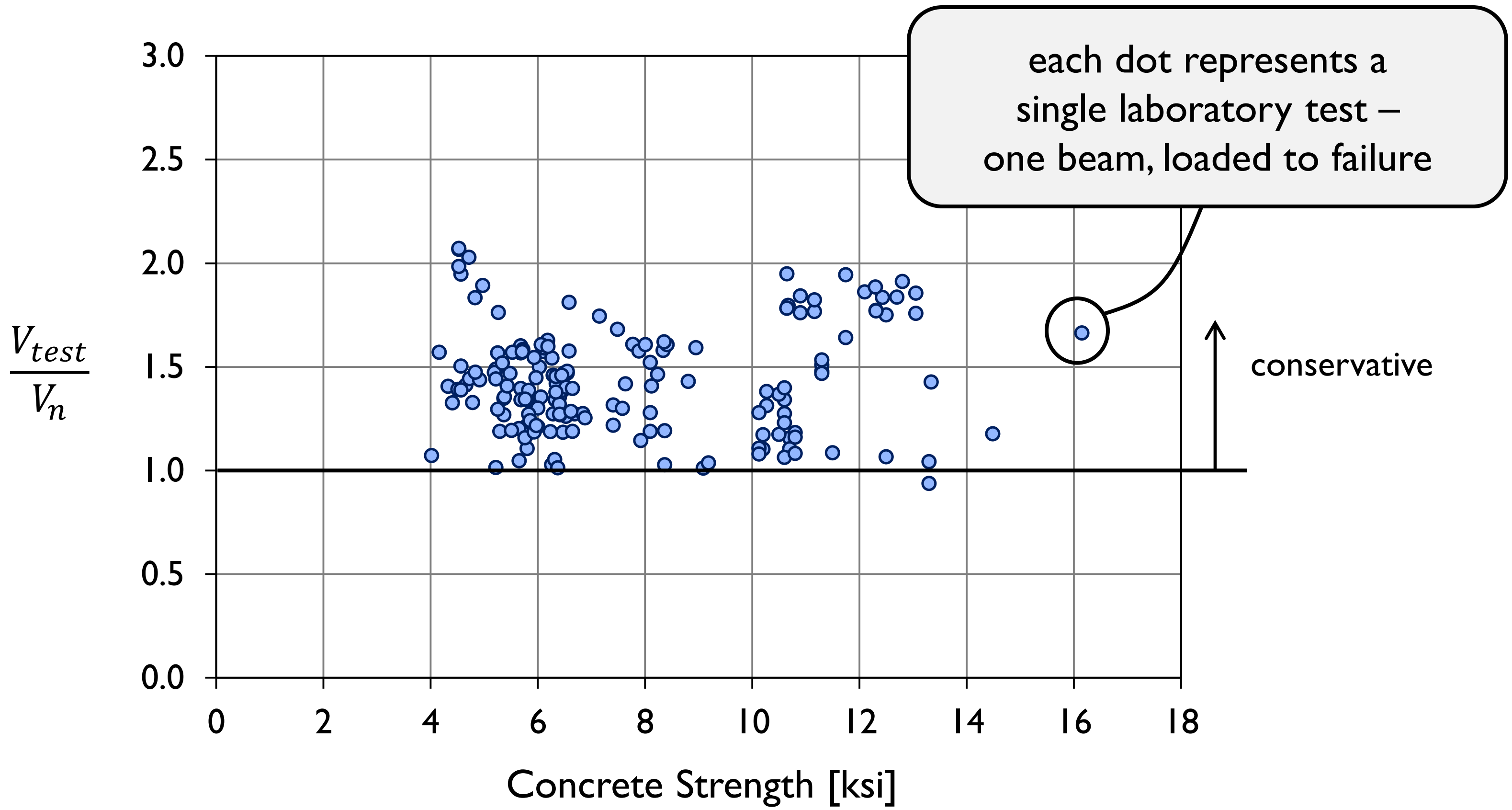
Used to create an Evaluation Database answering the question – how accurate is the code equation for shear capacity?

Expectations:
Shear Strength



V_n calculated using AASHTO LRFD General Procedure (2010)

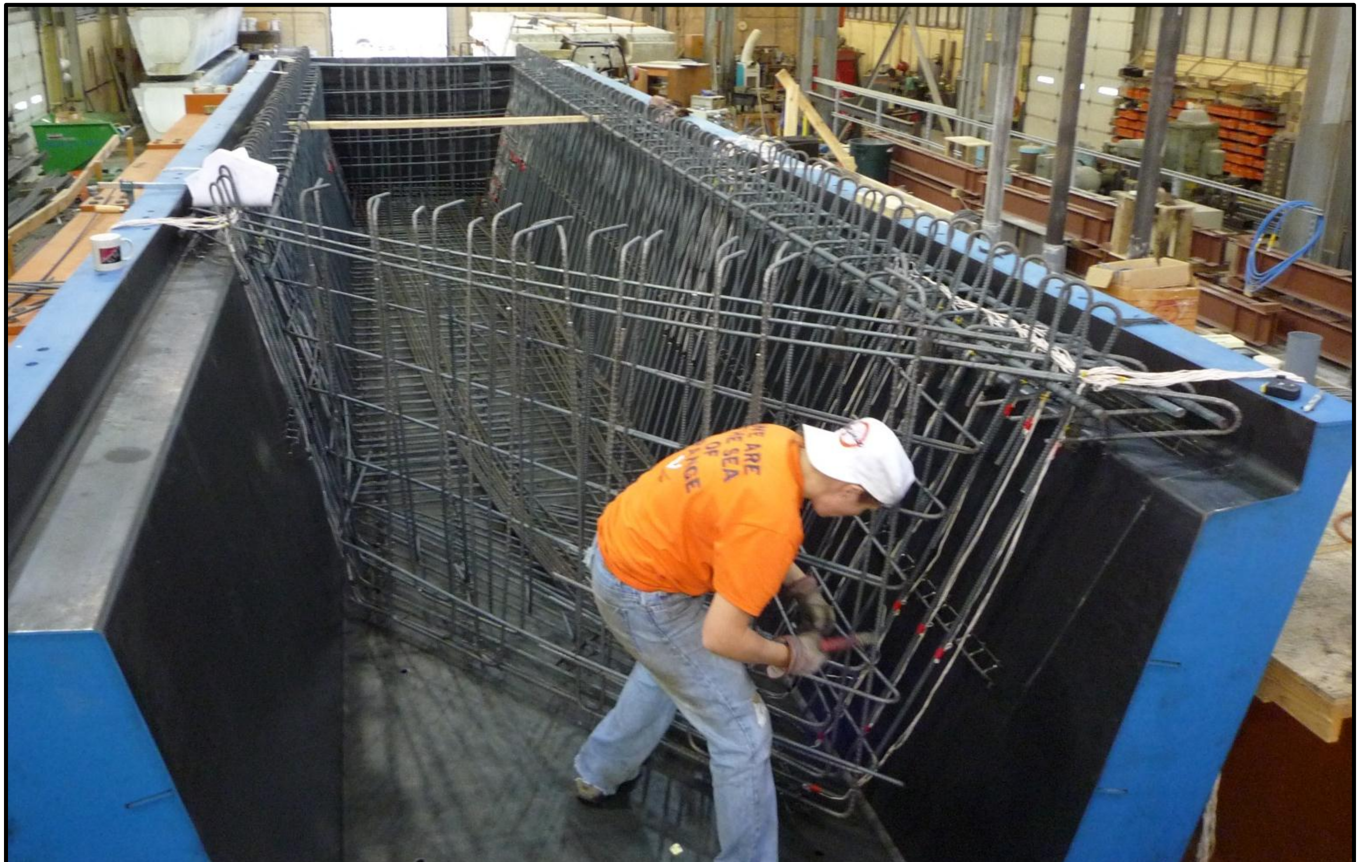
Expectations:
Shear Strength



V_n calculated using AASHTO LRFD General Procedure (2010)

Beam Fabrication

<u>tie reinforcement</u>



Beam Fabrication

place concrete: fill bottom slab

Beam Fabrication

place concrete: place void form

Beam Fabrication

place concrete: fill webs

Beam Fabrication

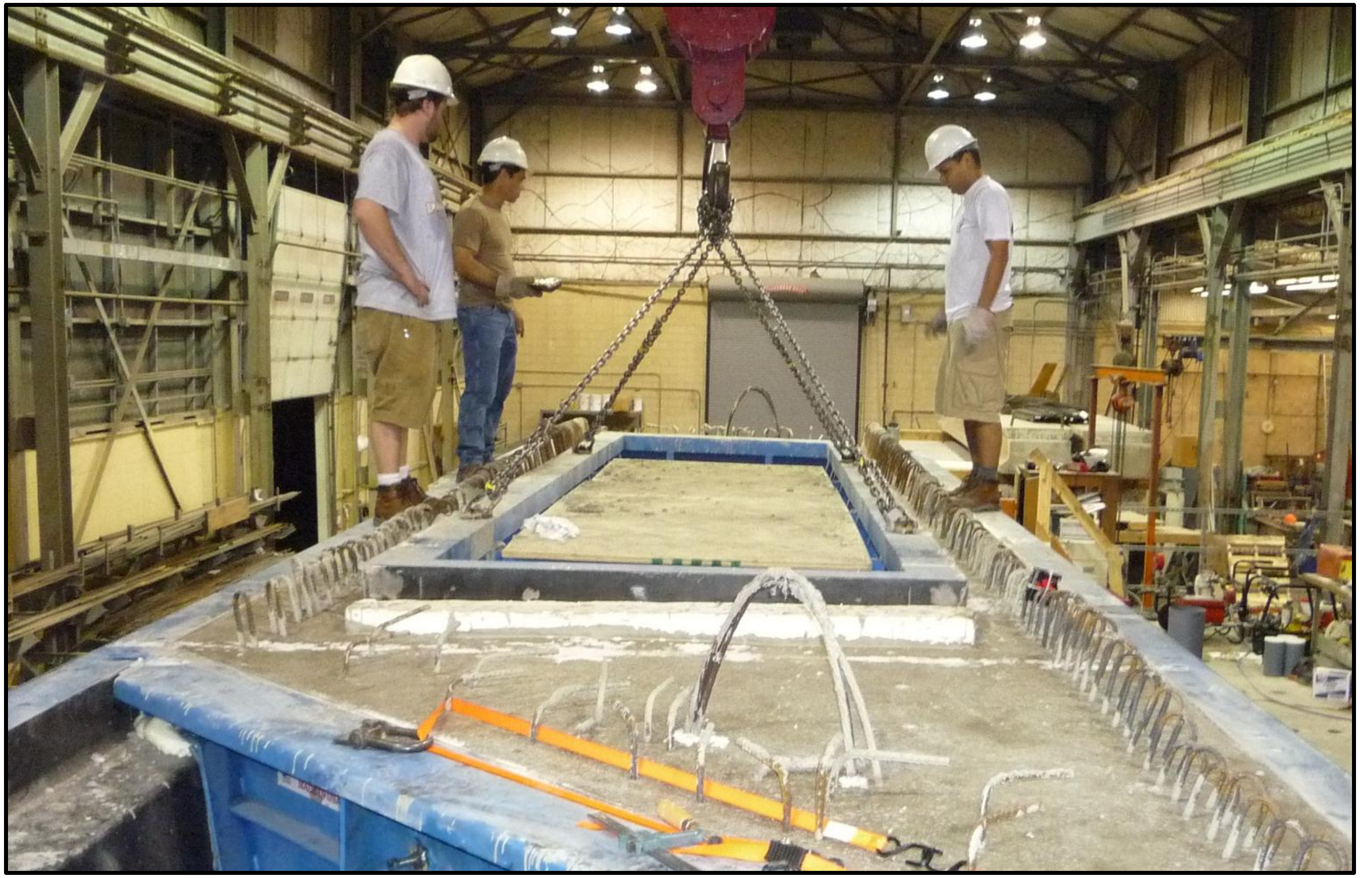
place concrete: clean up

Beam Fabrication

…wait…

Beam Fabrication

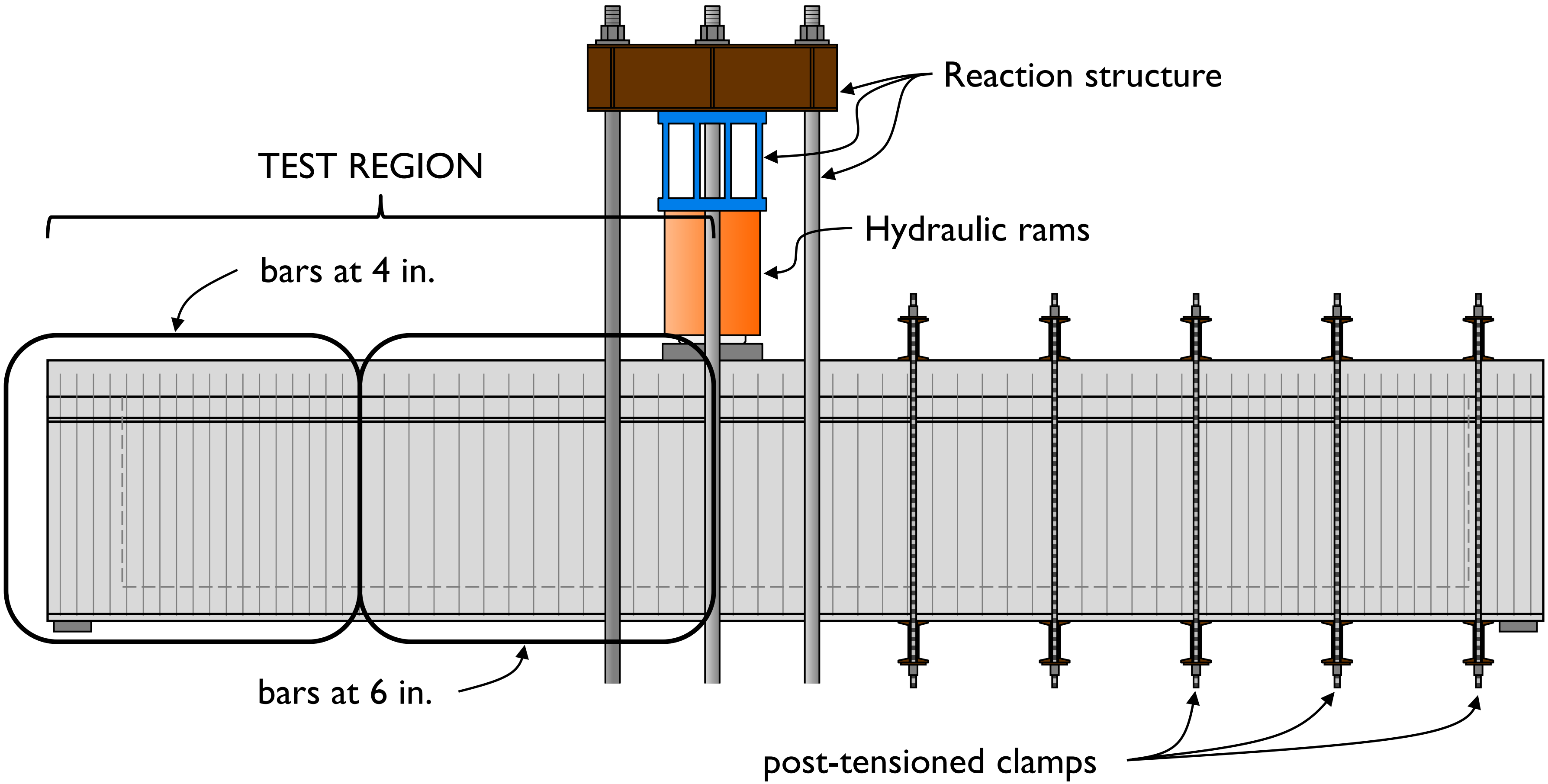
<u>strip forms</u>



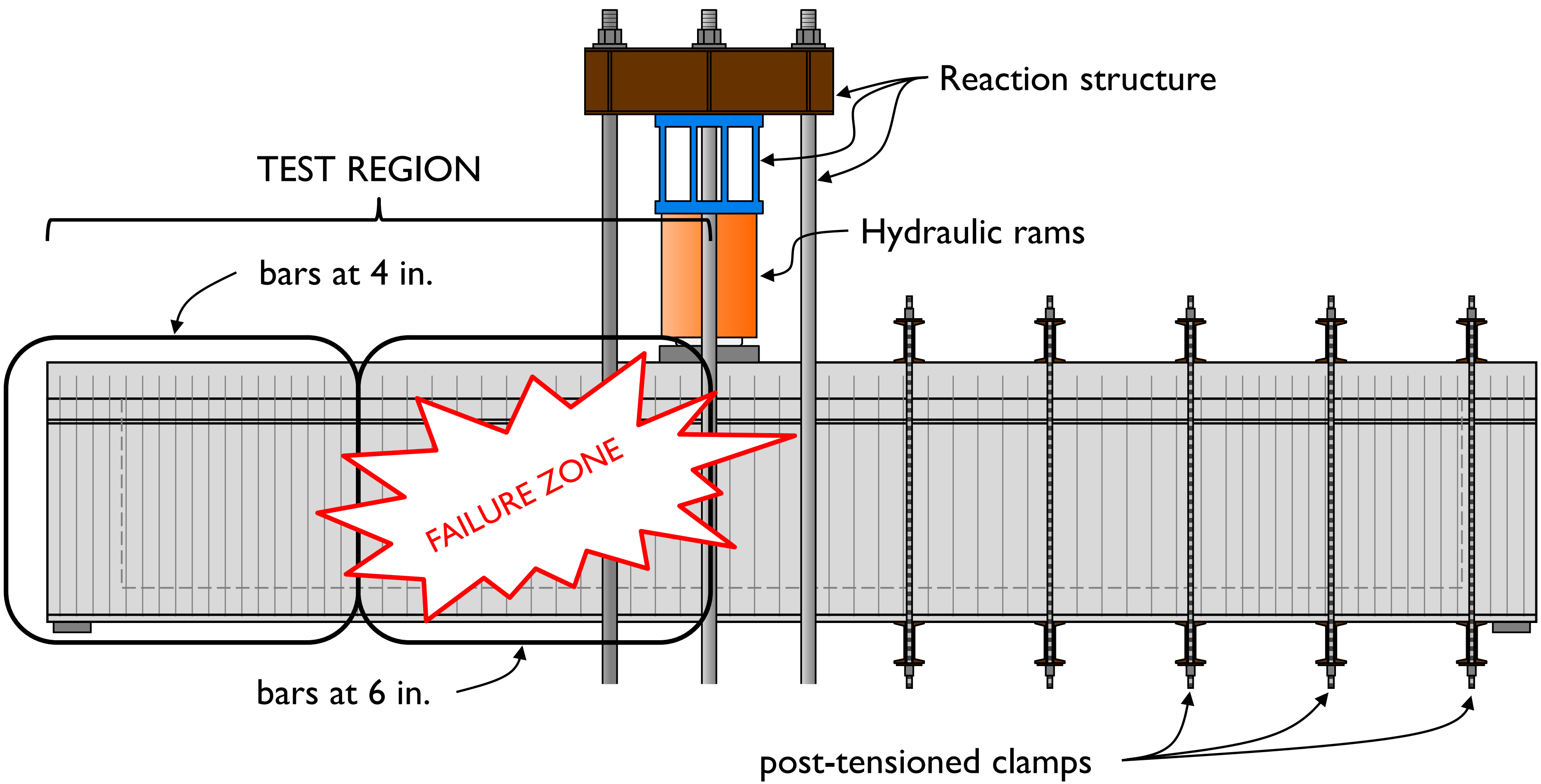
Beam Fabrication

beam is complete!

Shear Test Setup



Shear Test Setup

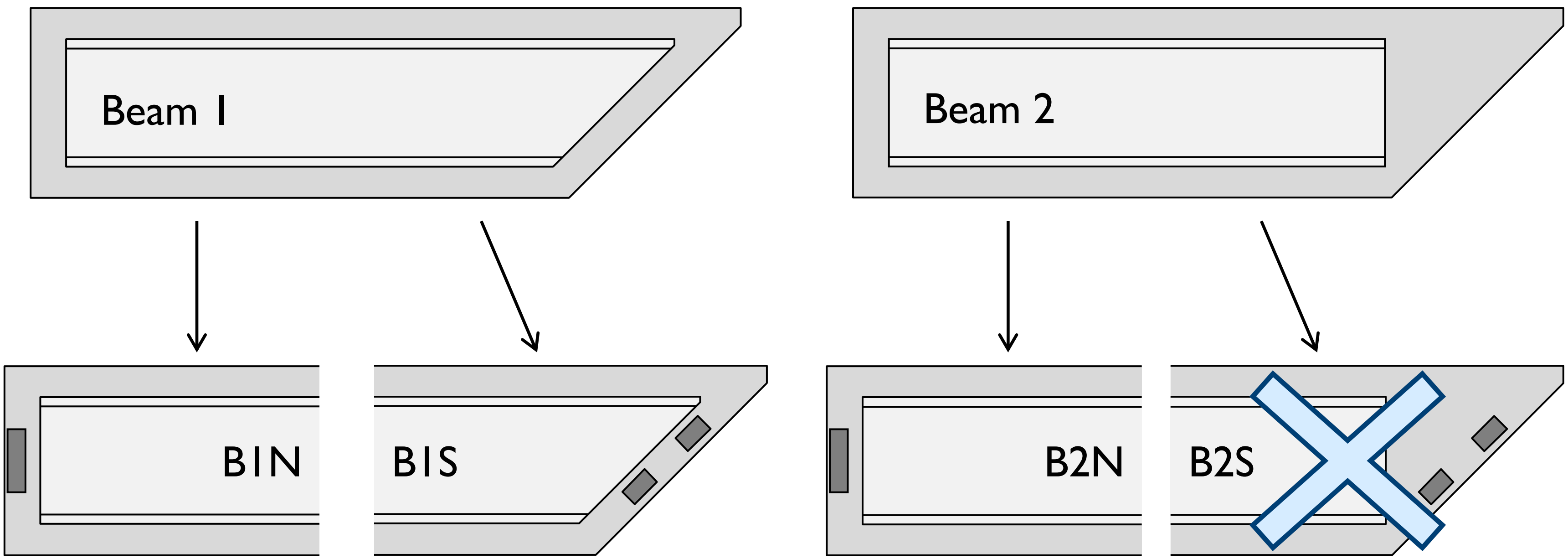


Shear Test Setup

STEP 1:

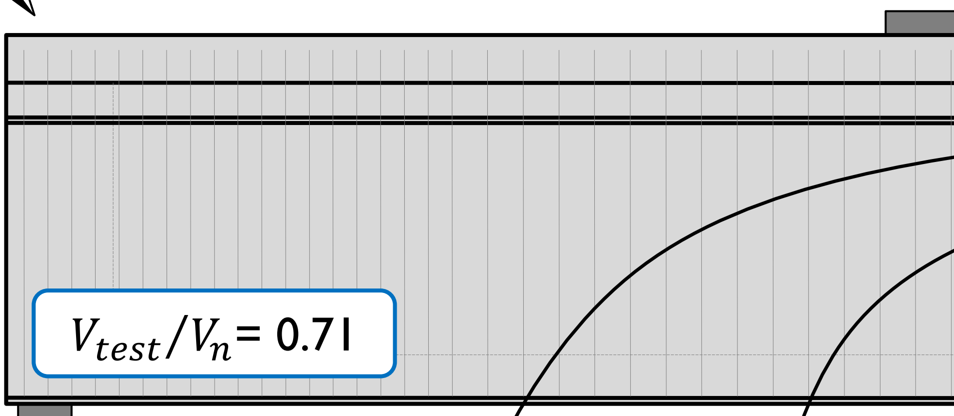
Establish Current Behavior

Beams 1 and 2



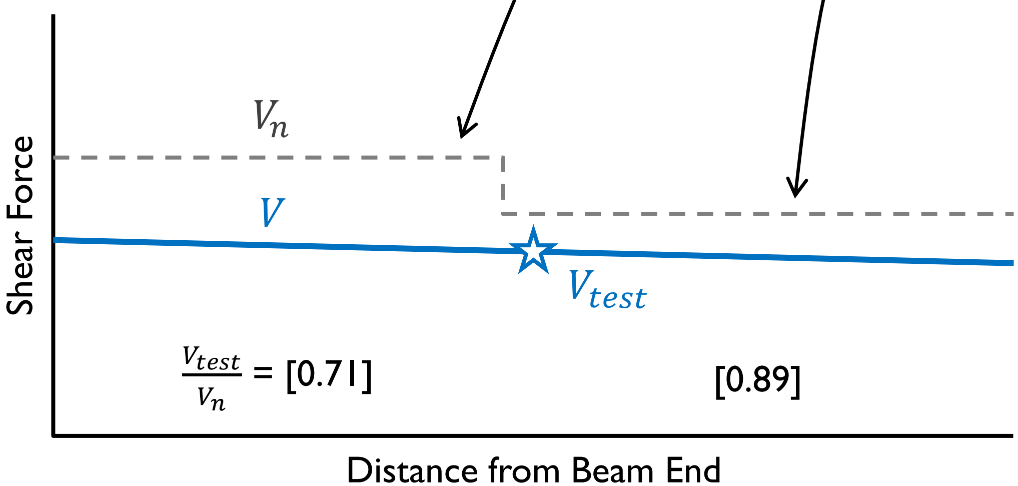
Failure could not be reached

Shear Performance: BIN

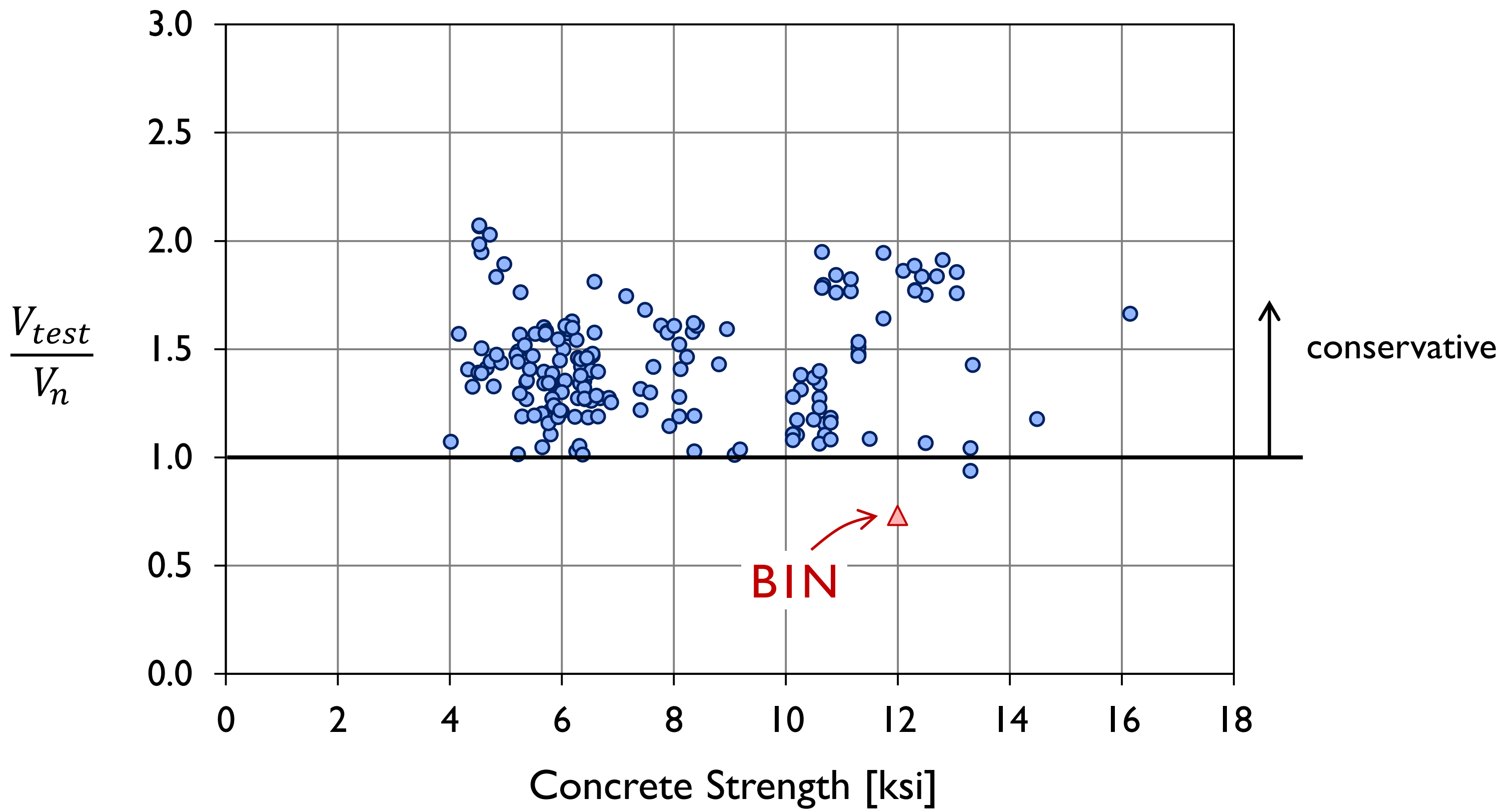


#4 stirrups spaced at:

- 4 in. for 6'-3"
- 6 in. for 7'-1"



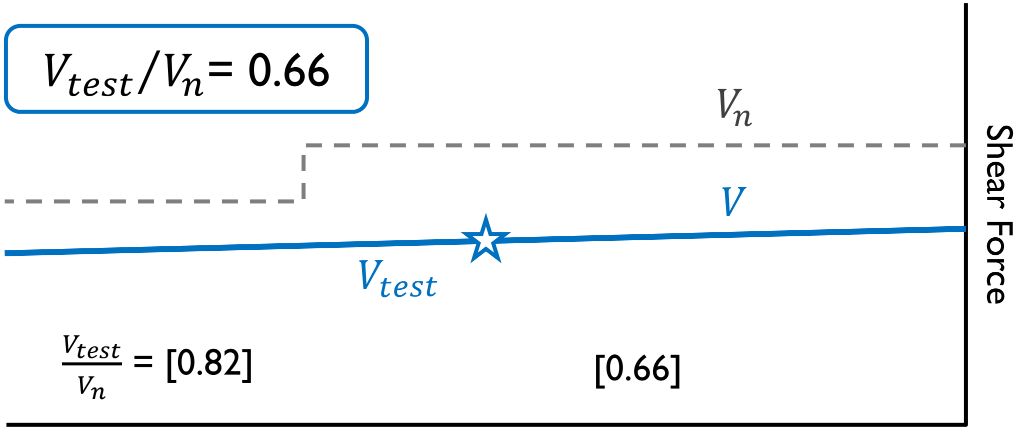
Shear Performance: BIN

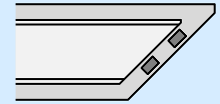


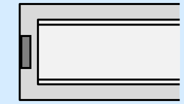
V_n calculated using AASHTO LRFD General Procedure (2010)

Shear Performance: B1S & B2N

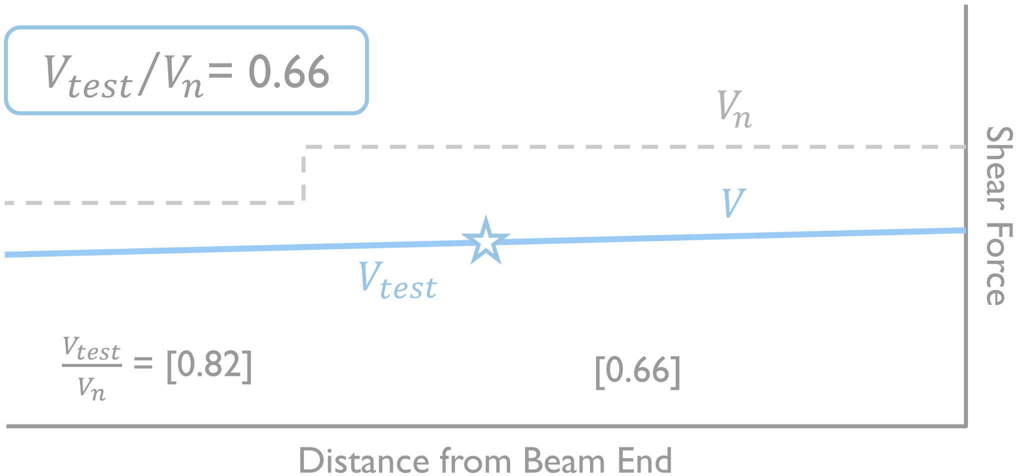
$V_{test}/V_n = 0.66$

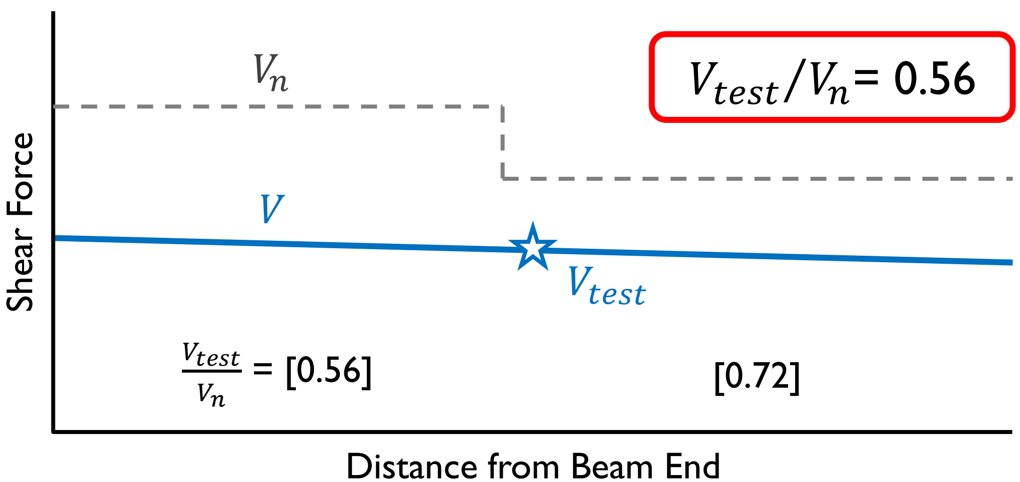




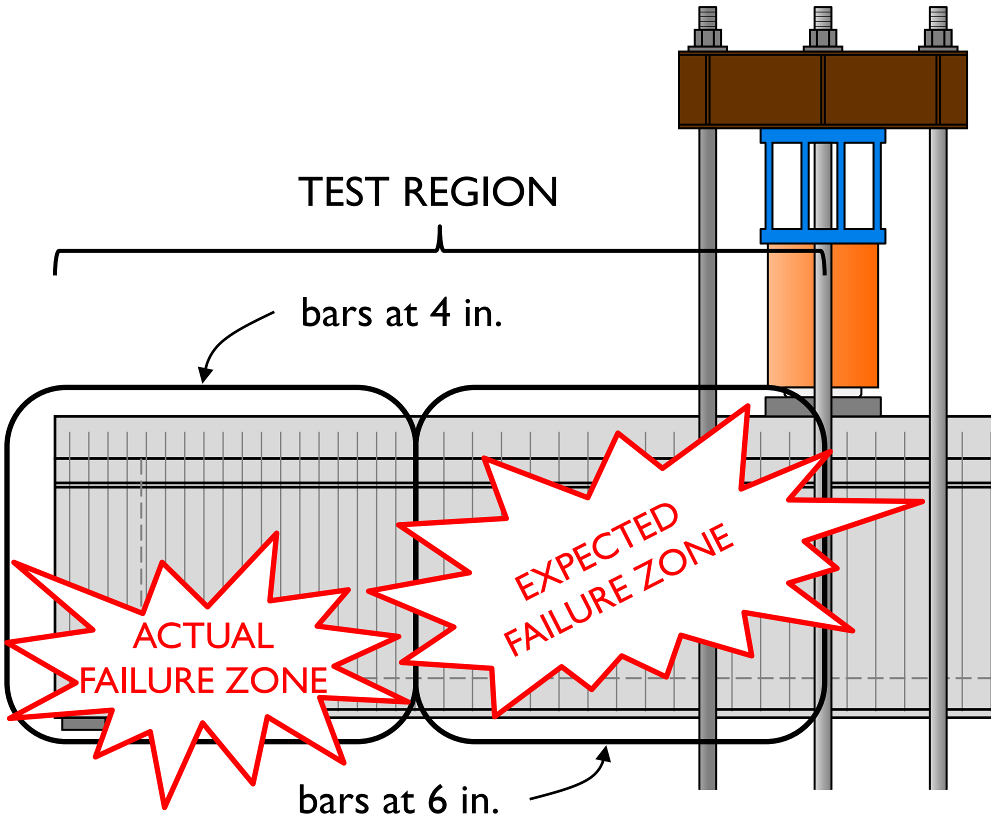


Shear Performance: B1S & B2N

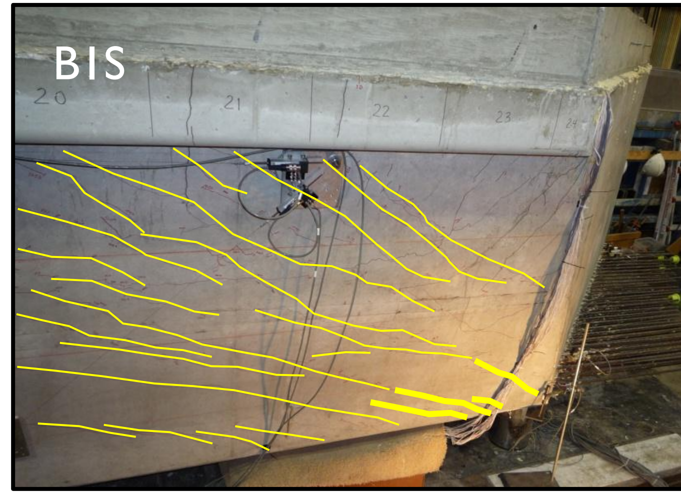




Shear Test Setup



V_{test}/V_n = 0.71, 0.66, 0.56

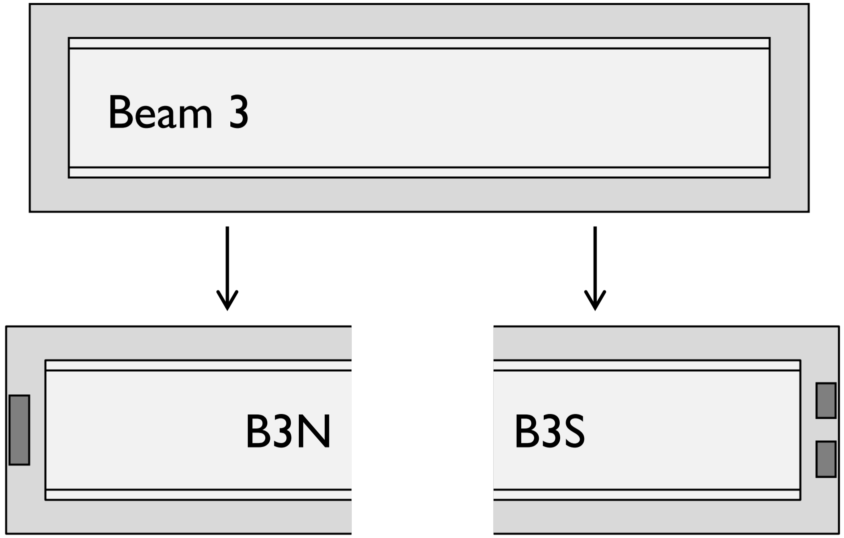


Intermediate Analysis

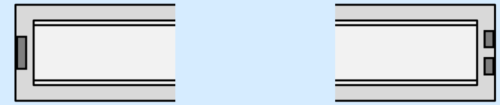
- These beams are not failing in web-shear

  Comparing failure shear with code web-shear capacity is inappropriate

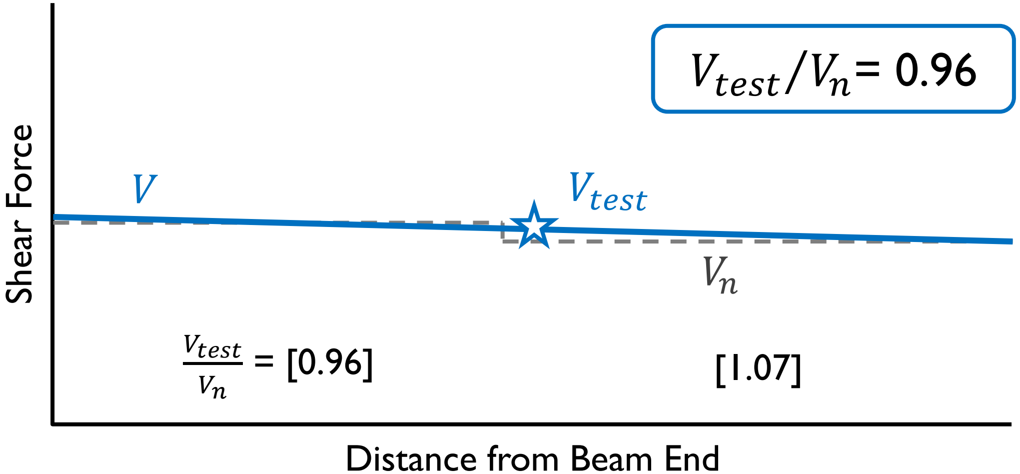
- Are we testing the worst-case scenario?

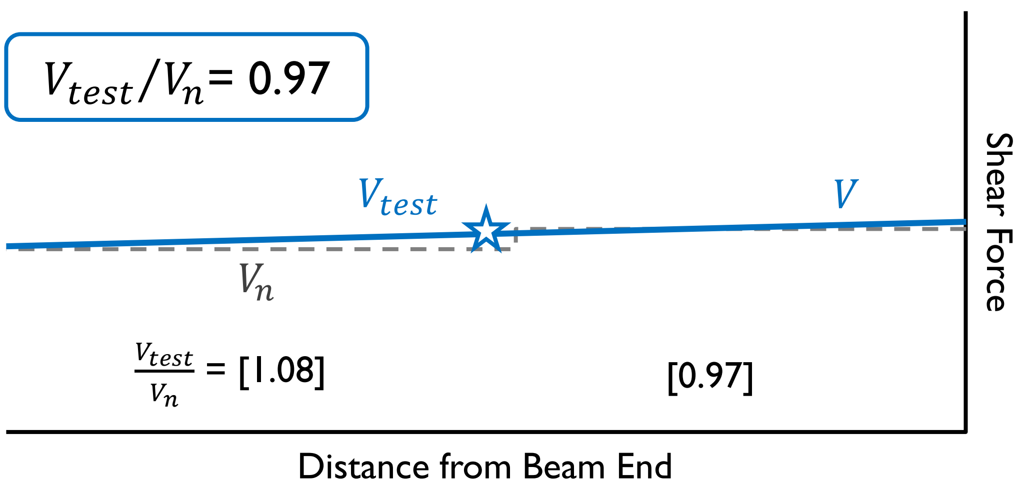


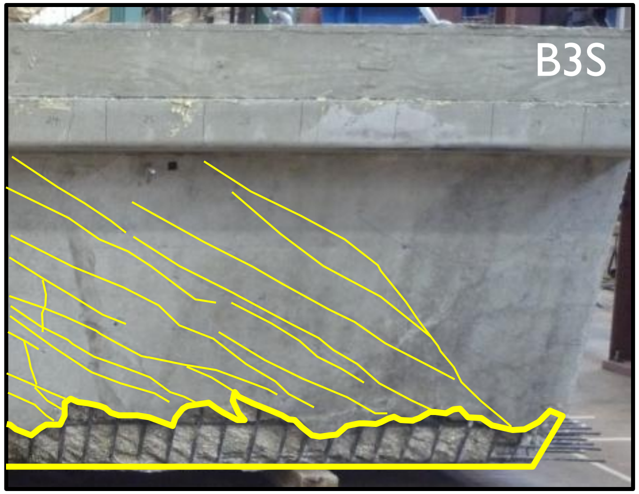
Contains 42 0.5-in. strands (instead of 78)



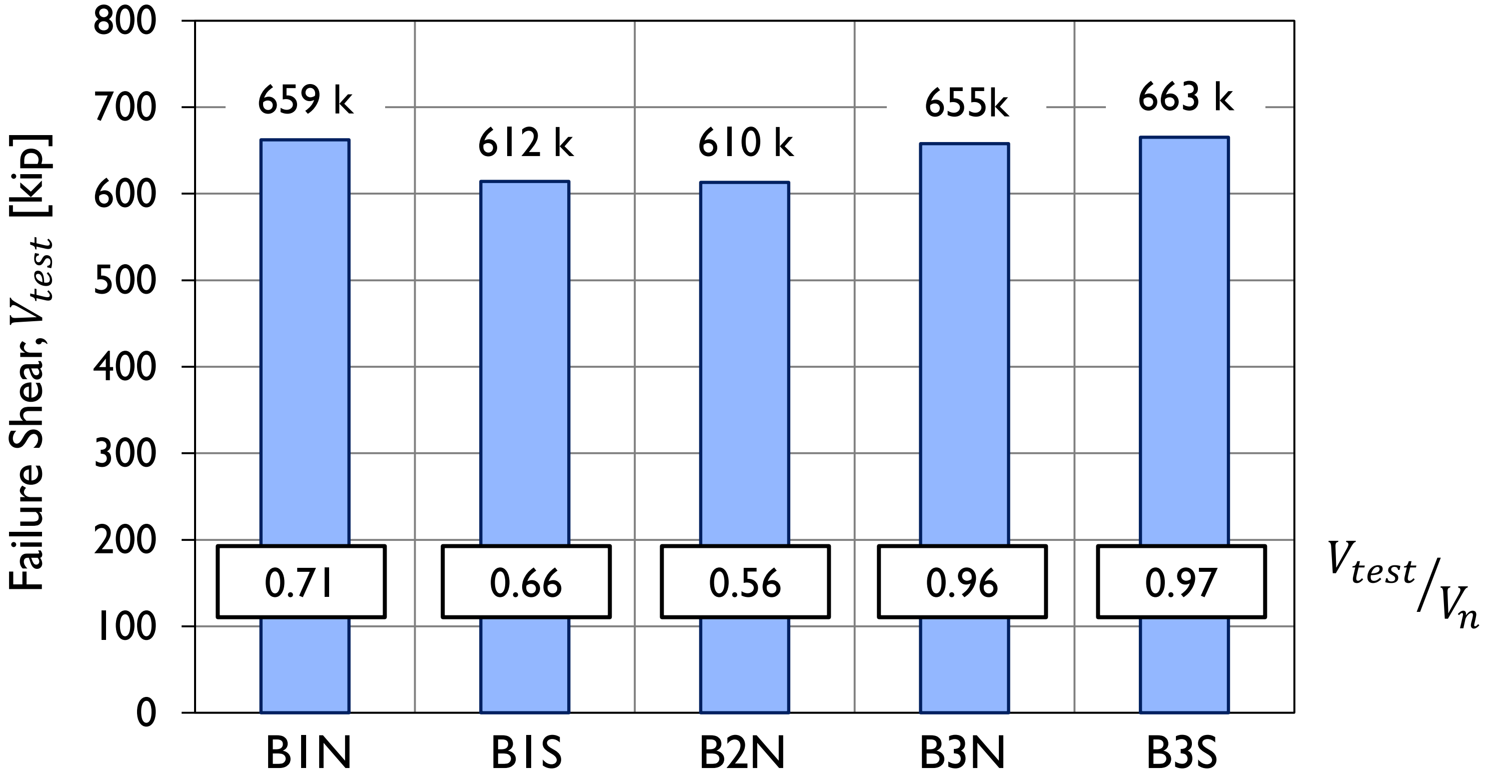
Shear Performance: B3N & B3S



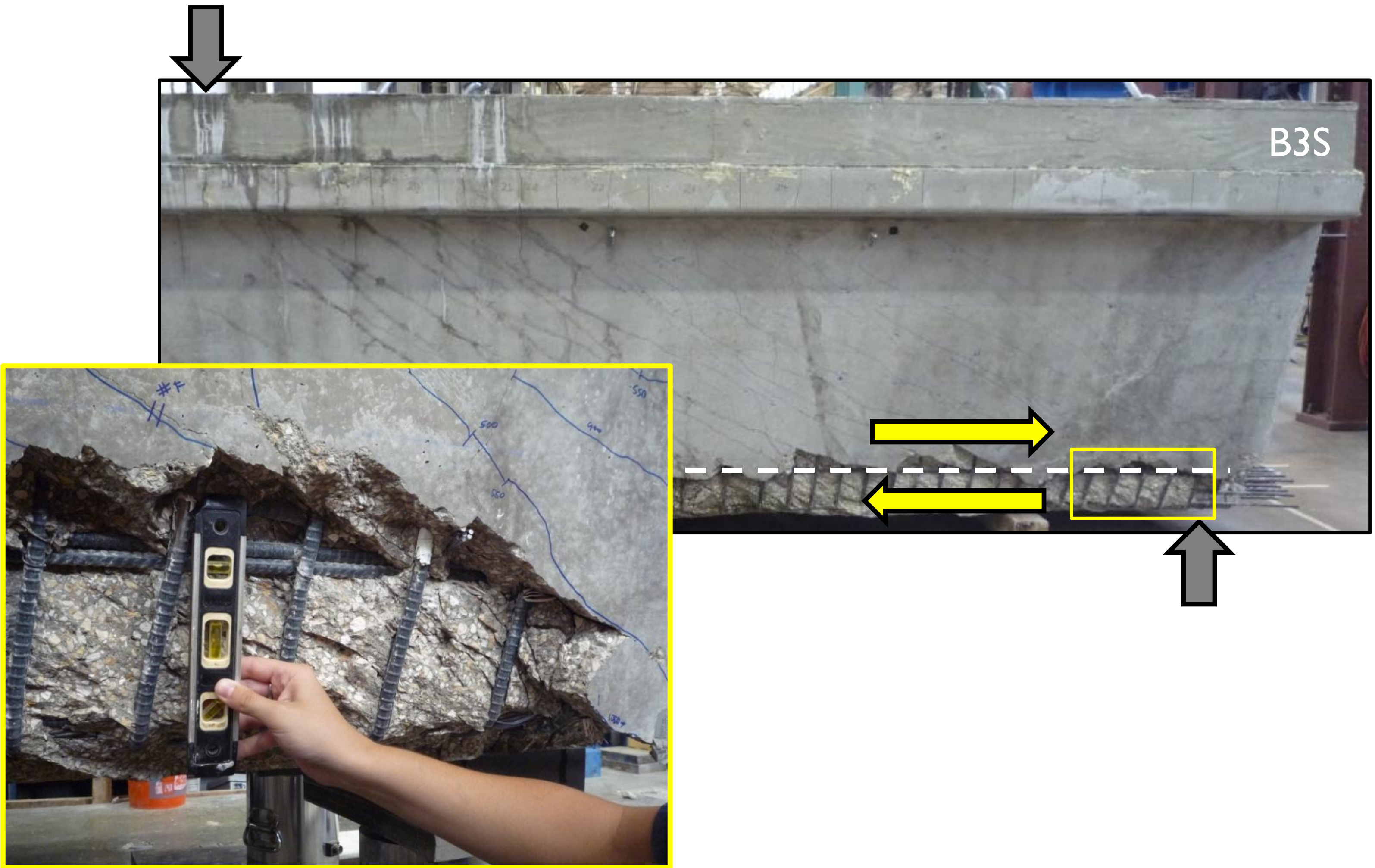




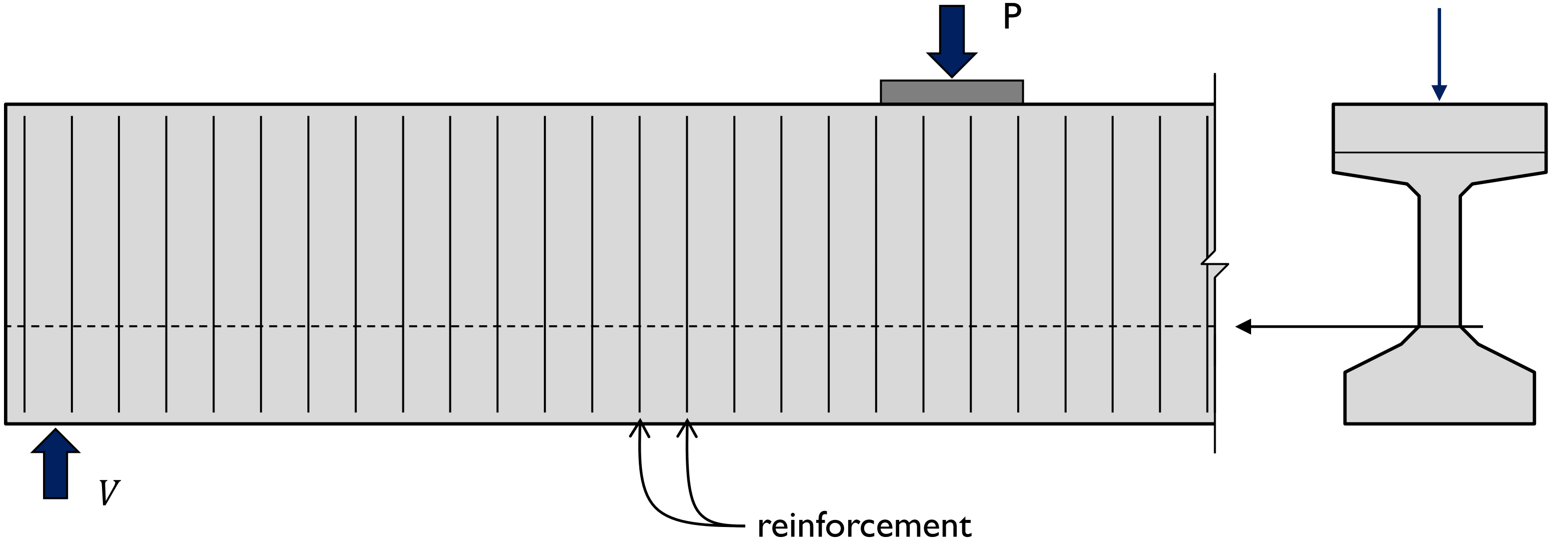
Comparison of Failure Shears



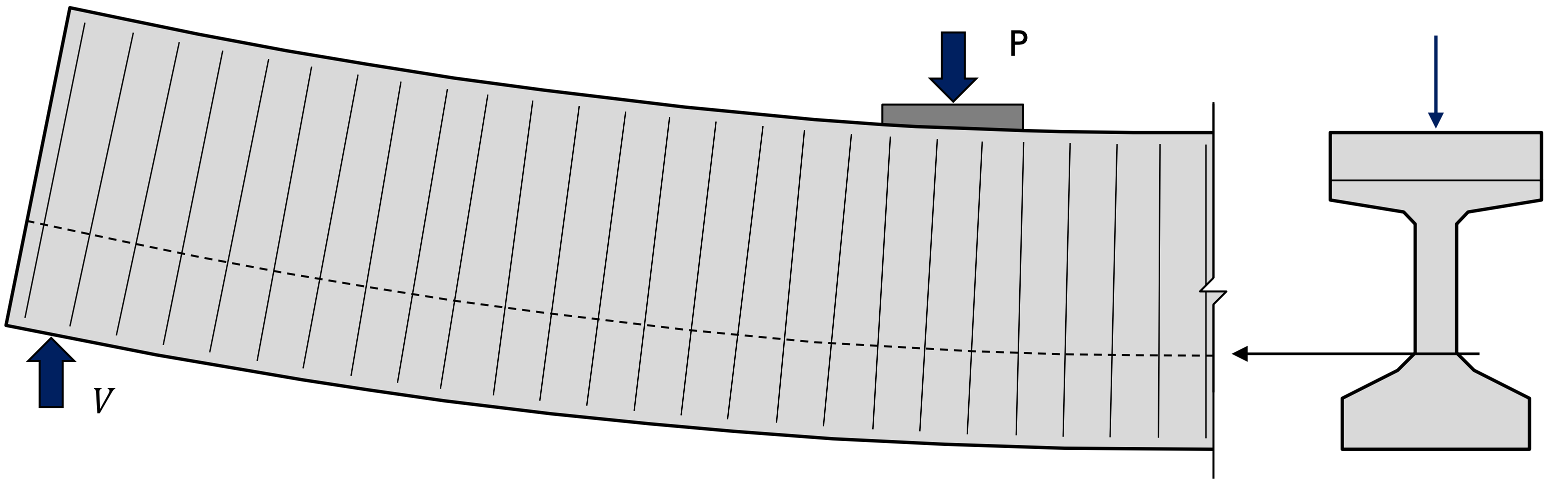
Shear Performance: B3S



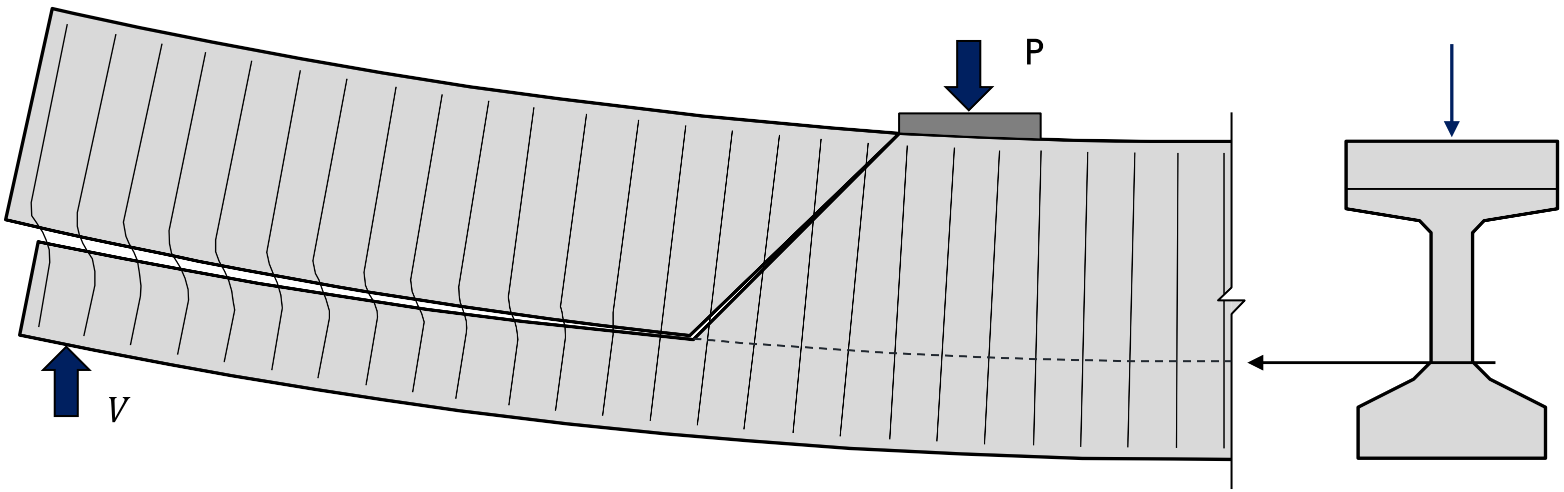
Horizontal Shear



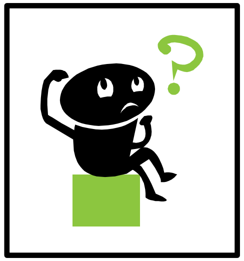
Horizontal Shear



Horizontal Shear



Flow of Test Program



Can we optimize the end-region of Texas U-Beams?

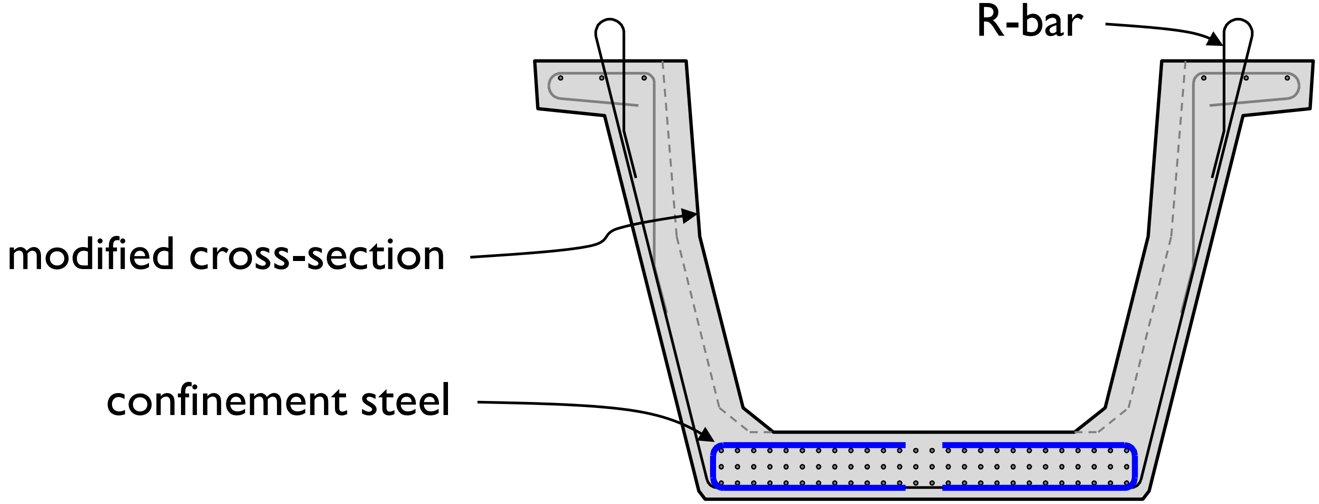
- ease construction
- maintain structural performance

Can we improve the end-region design of Texas U-Beams to increase horizontal shear capacity and allow web-shear to control behavior?

STEP 2:

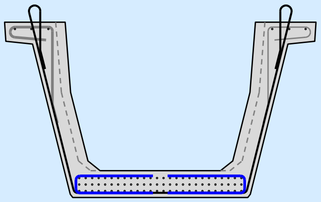
Design Beams for Better Behavior

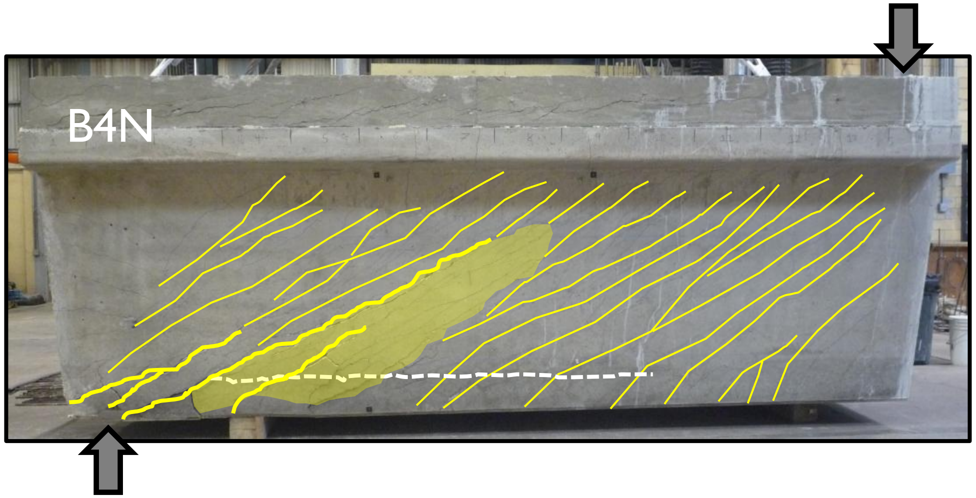
Test Region B4N



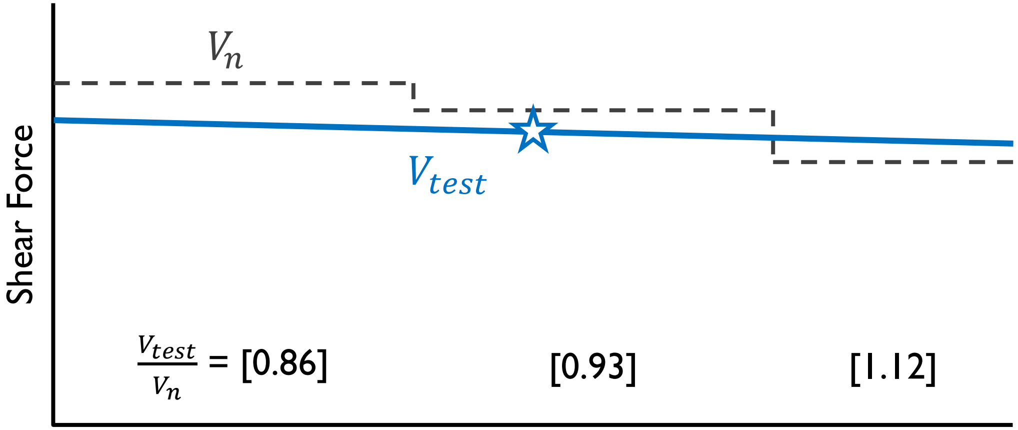
#4 R-bars spaced at 3 in. for 5'-0"
4 in. for 5'-0"
6 in. for 3'-4"

Test Region B4N





← horizontal shear with some web crushing

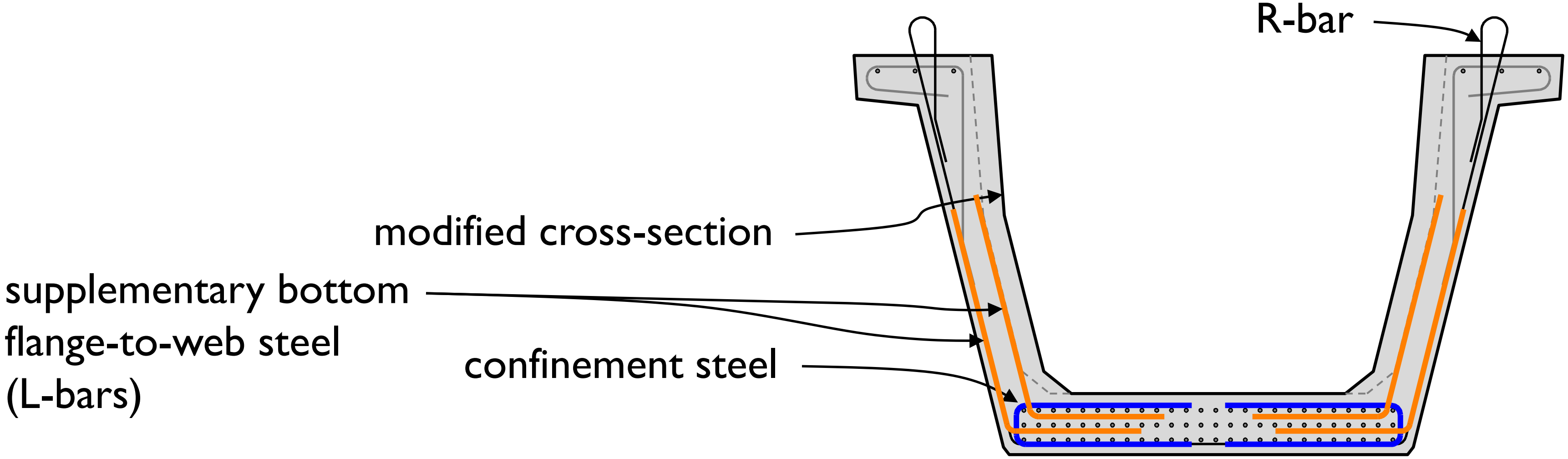


#4 R-bars spaced at

3 in. for 5'-0"
4 in. for 5'-0"
6 in. for 3'-4"

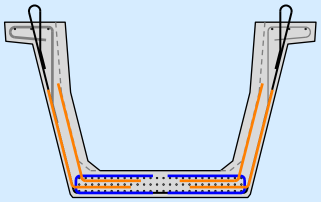
$V_{test}/V_n = 0.86$

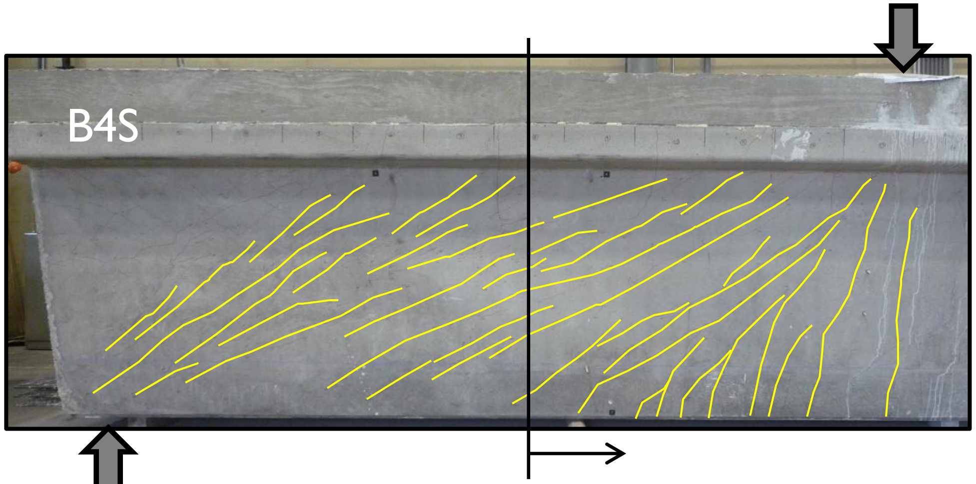
Test Region B4S



#4 R-bars spaced at	3 in. for 5'-0"
	4 in. for 5'-0"
	6 in. for 3'-4"
3-#5 L-bars spaced at	3 in. for 5'-0"
	4 in. for 2'-8"

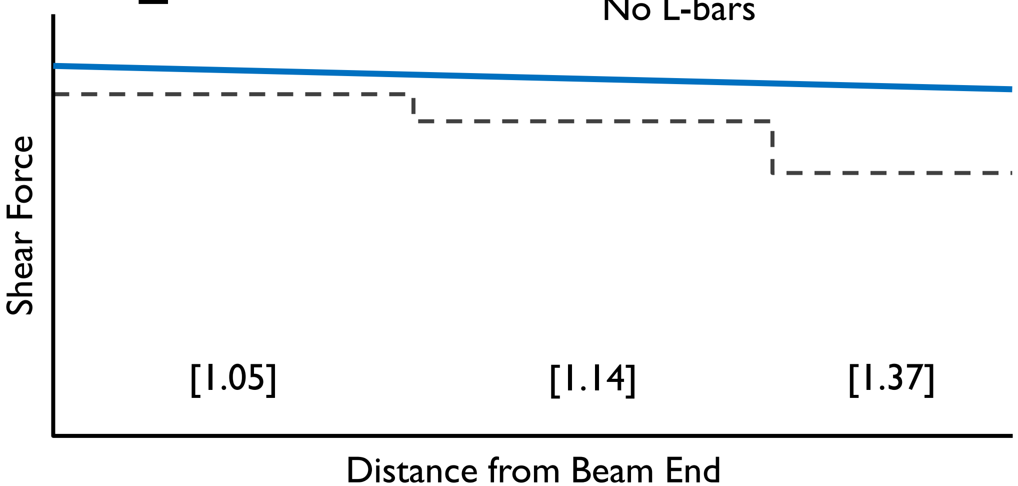
Test Region B4S





test halted
before failure

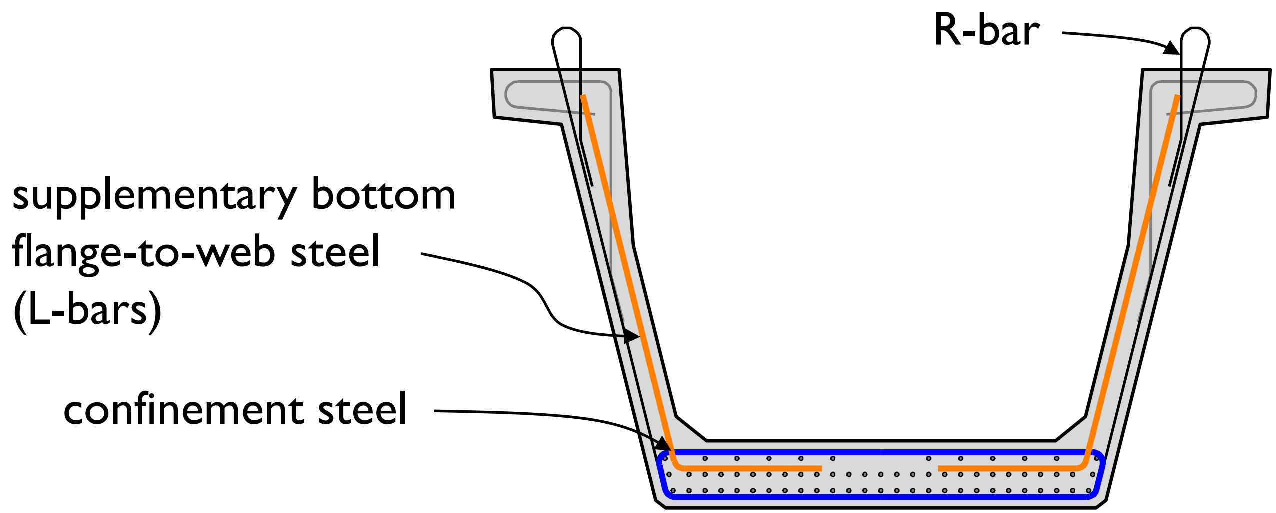
No L-bars



#4 R-bars spaced at	3 in. for 5'-0"
	4 in. for 5'-0"
	6 in. for 3'-4"
3-#5 L-bars spaced at	3 in. for 5'-0"
	4 in. for 2'-8"

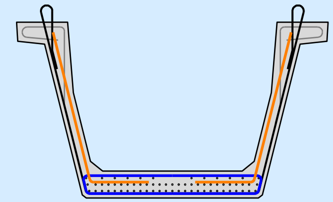
V_{test}/V_n = 1.37

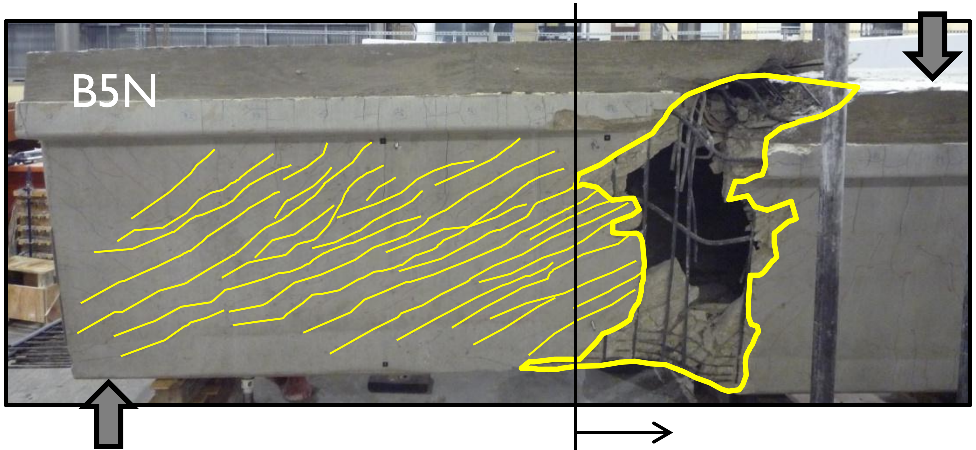
Test Region B5N



#5 R-bars spaced at	4 in. for 8'-3"
	6 in. for 5'-1"
#6 L-bars spaced at	4 in. for 8'-3"

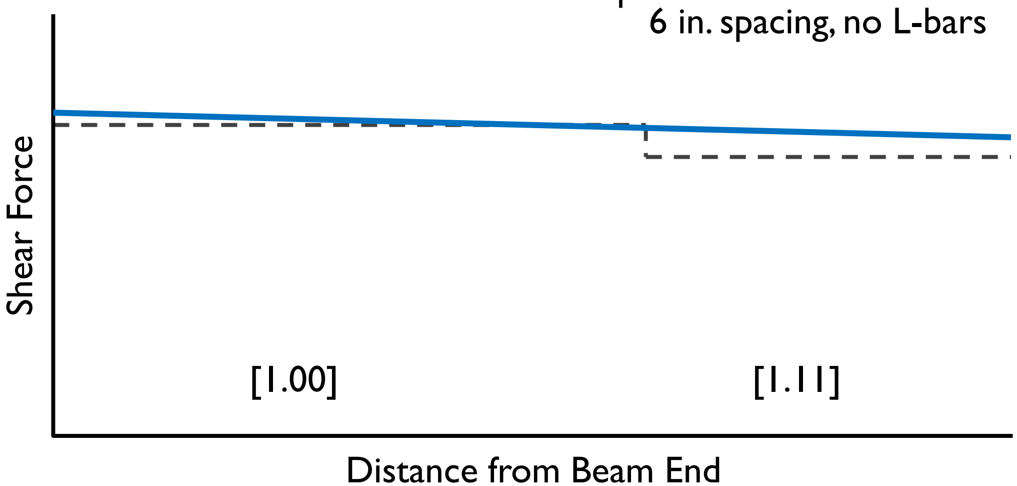
Test Region B5N





← flexure-shear

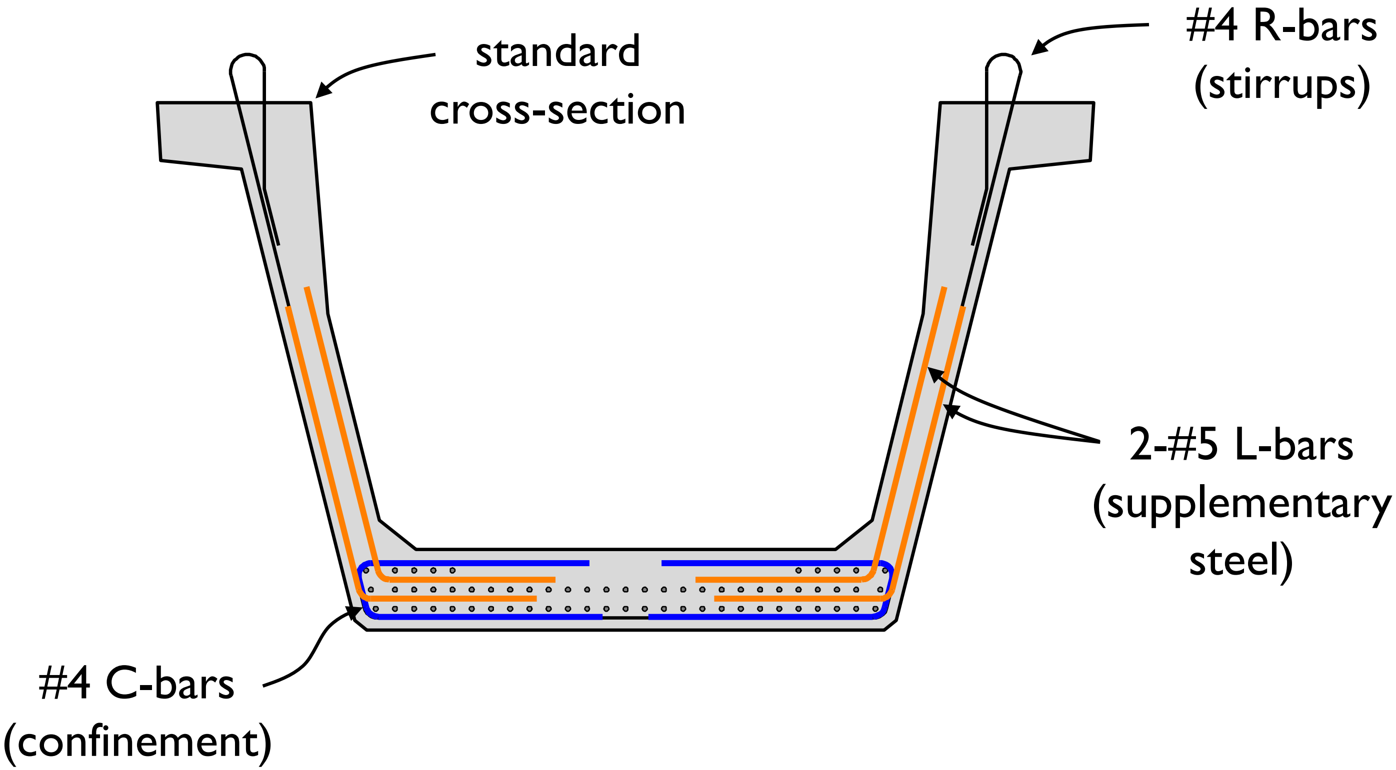
6 in. spacing, no L-bars



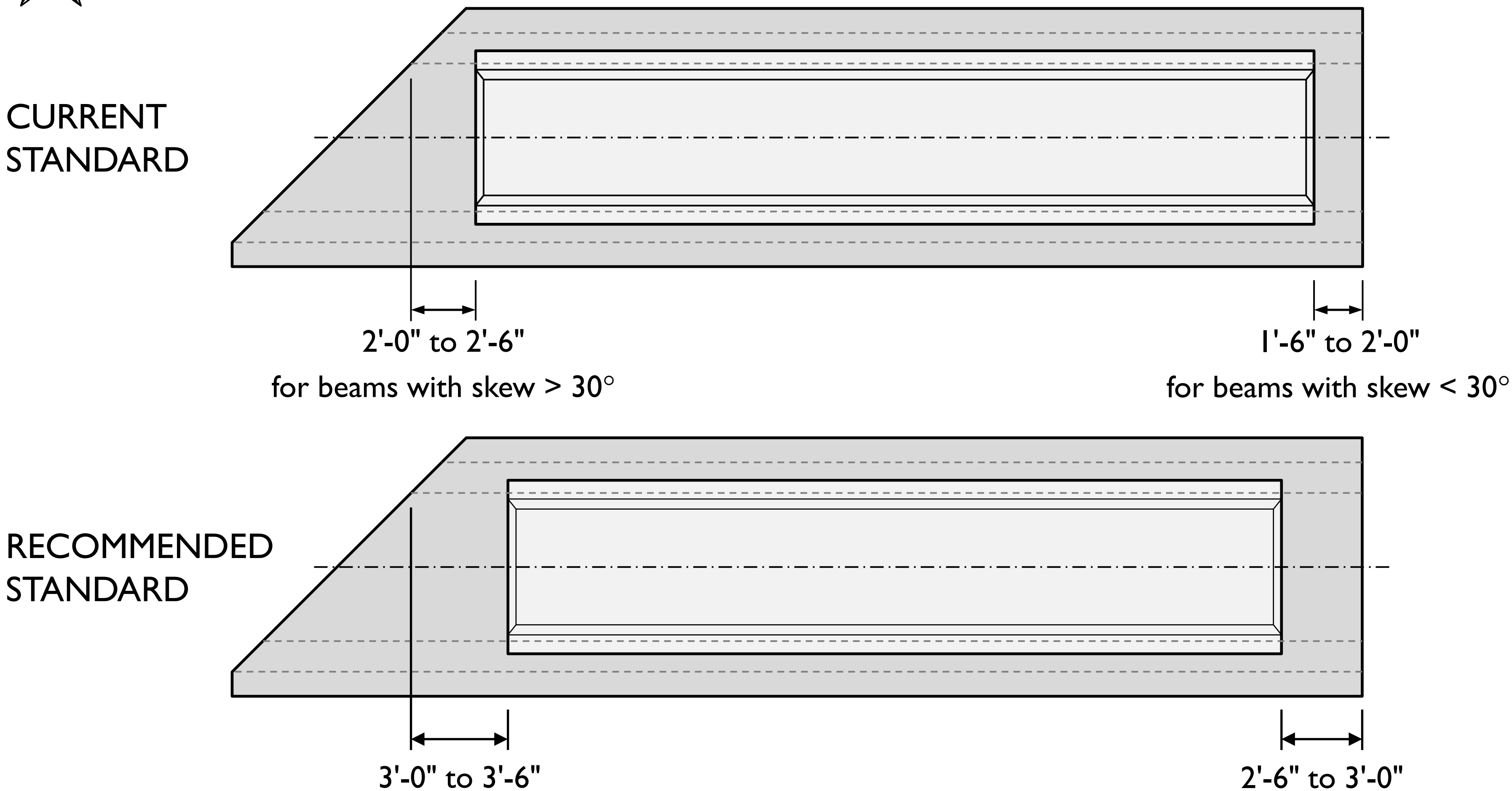
#5 R-bars spaced at	4 in. for 8'-3"
	6 in. for 5'-1"
#6 L-bars spaced at	4 in. for 8'-3"

$V_{test}/V_n = 1.11$

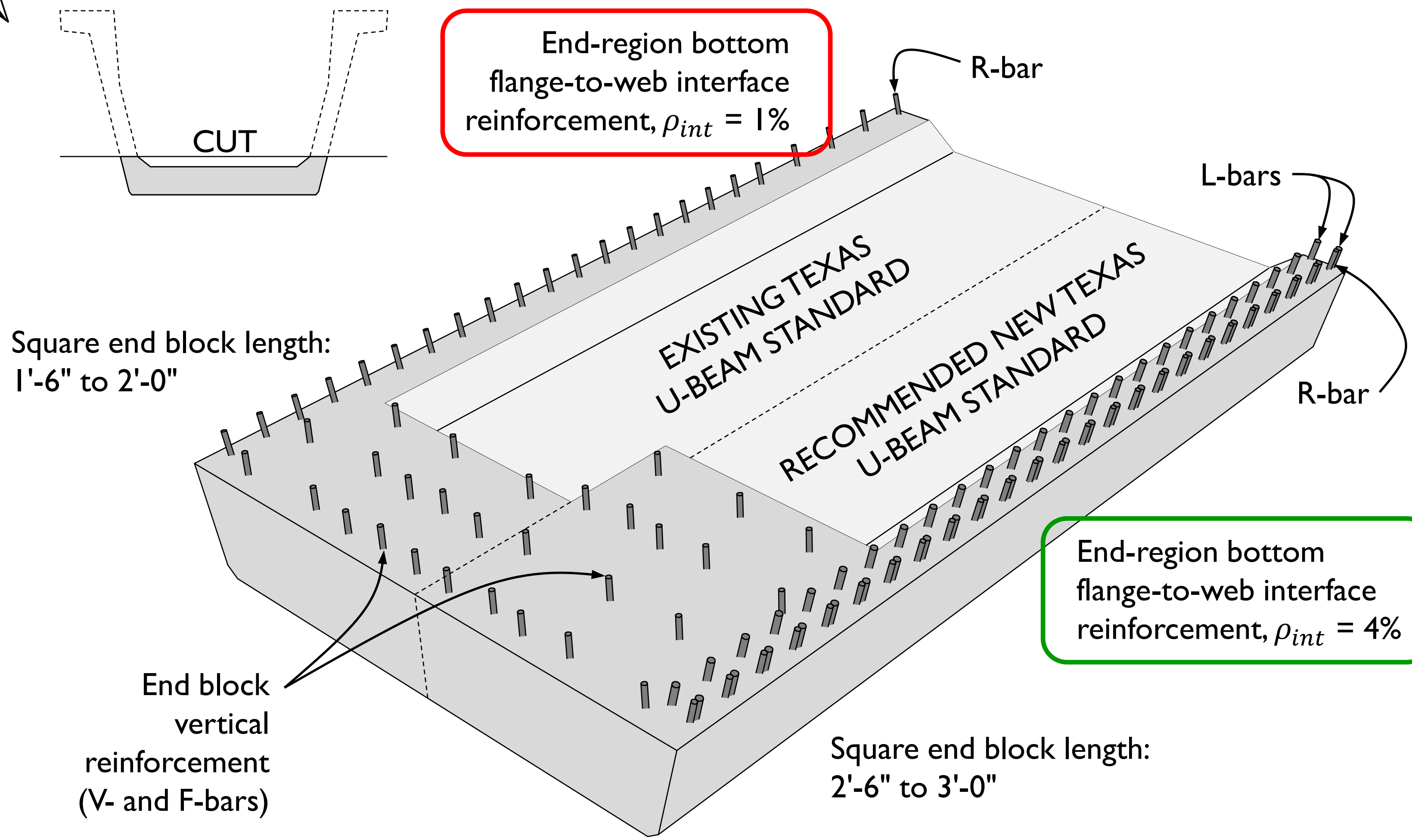
Recommended New Design



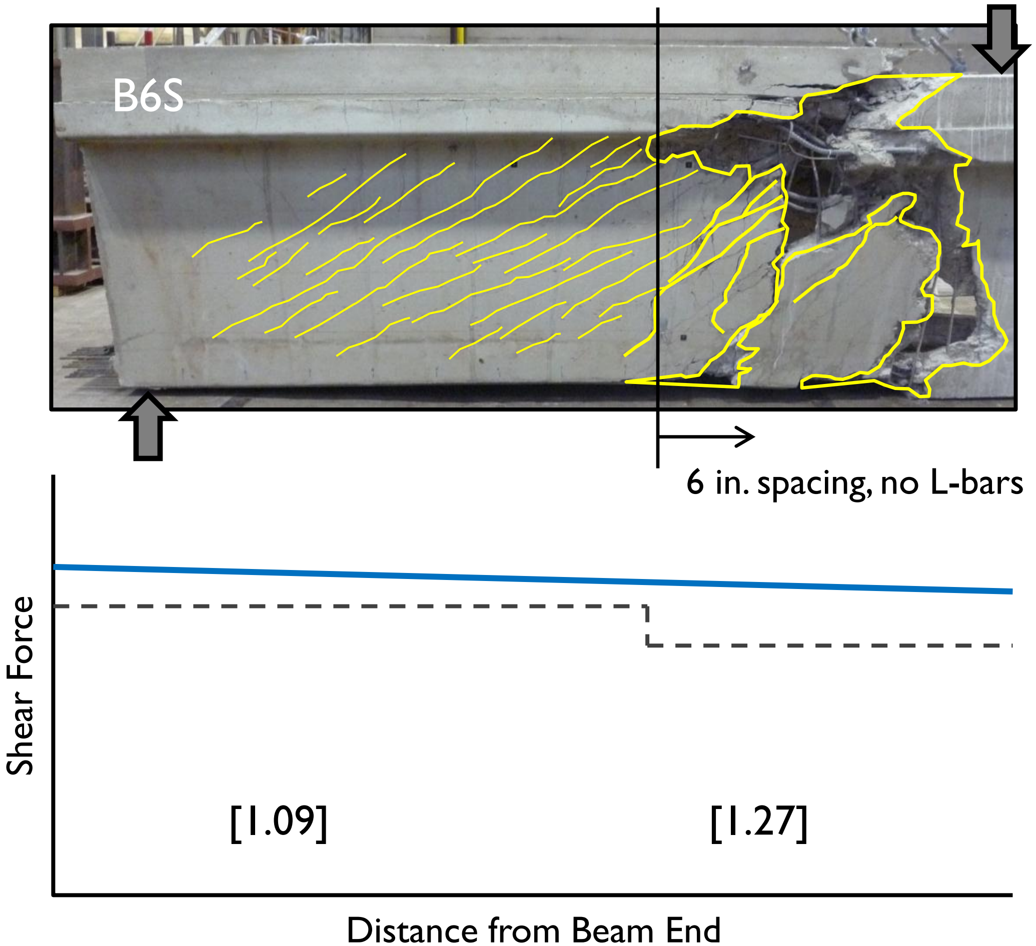
Recommended New Design



Recommended New Design



Test Region B6S



flexure-shear

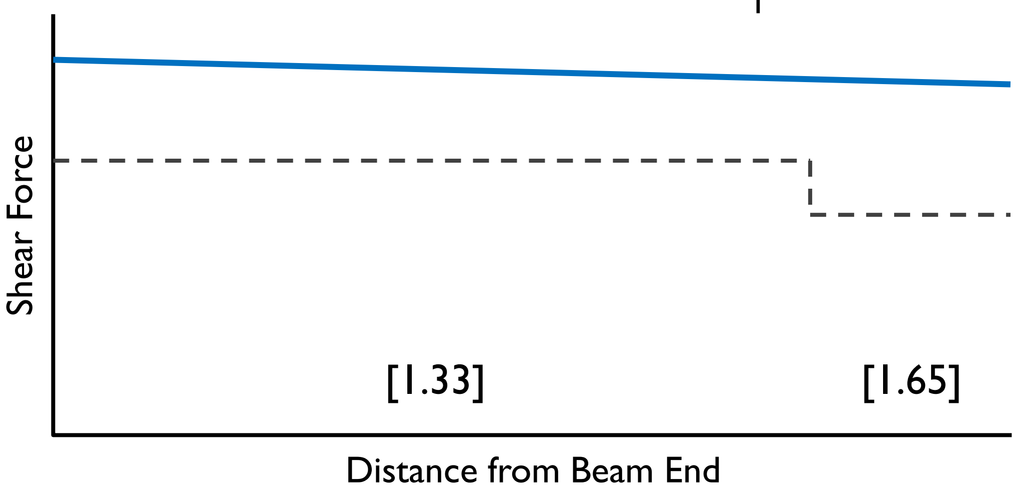
#4 R-bars spaced at		4 in. for 8'-3"
		6 in. for 5'-1"
2-#5 L-bars spaced at		4 in. for 8'-3"

V_{test}/V_n = 1.27

Test Region B7N

web crushing

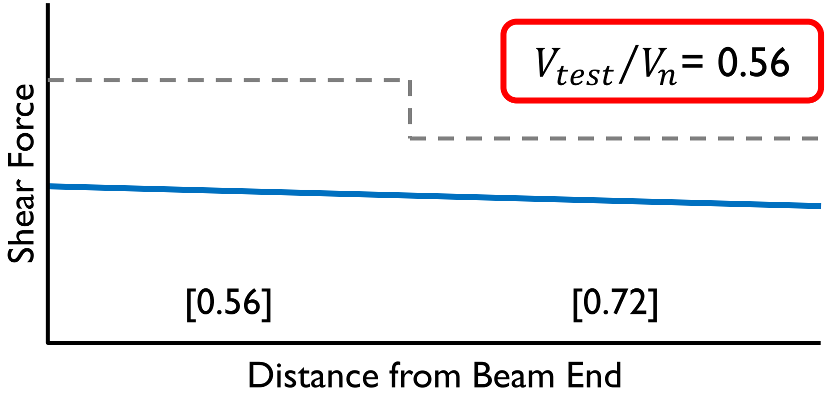
6 in. spacing, no L-bars

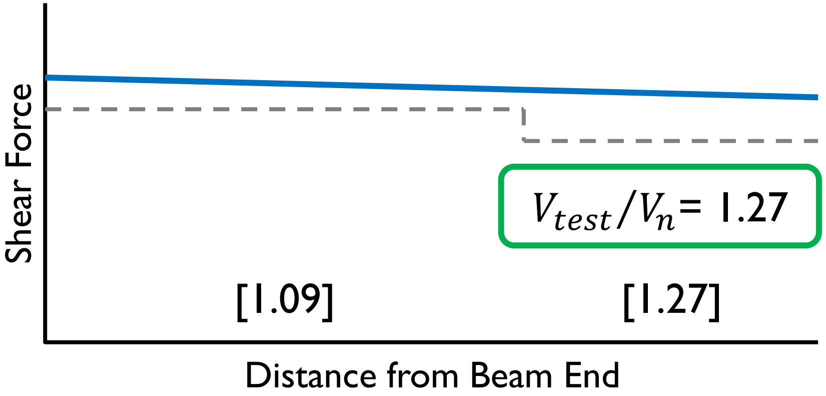


#4 R-bars spaced at	4 in. for 8'-3"
	6 in. for 5'-1"
2-#5 L-bars spaced at	4 in. for 8'-3"

V_{test}/V_n = 1.65

Effect of Design Changes

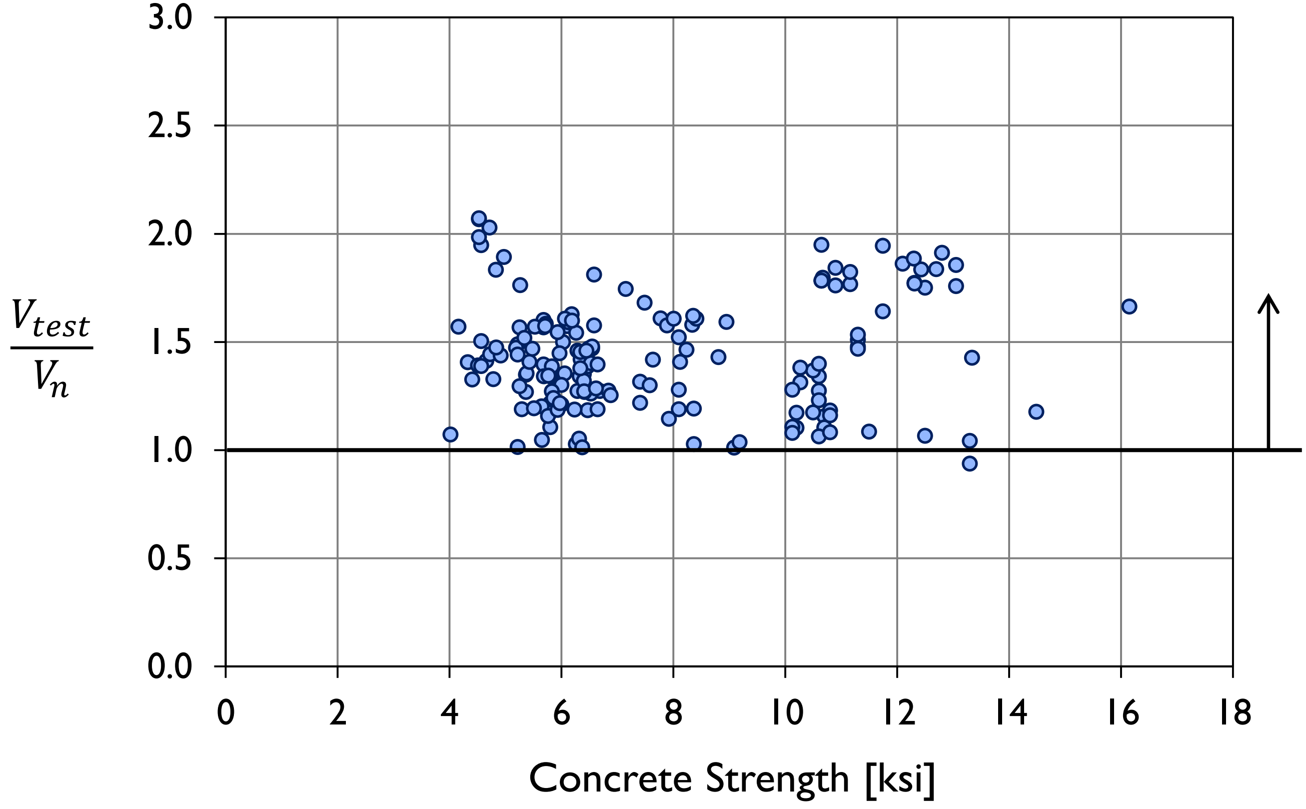




Horizontal Shear Failure

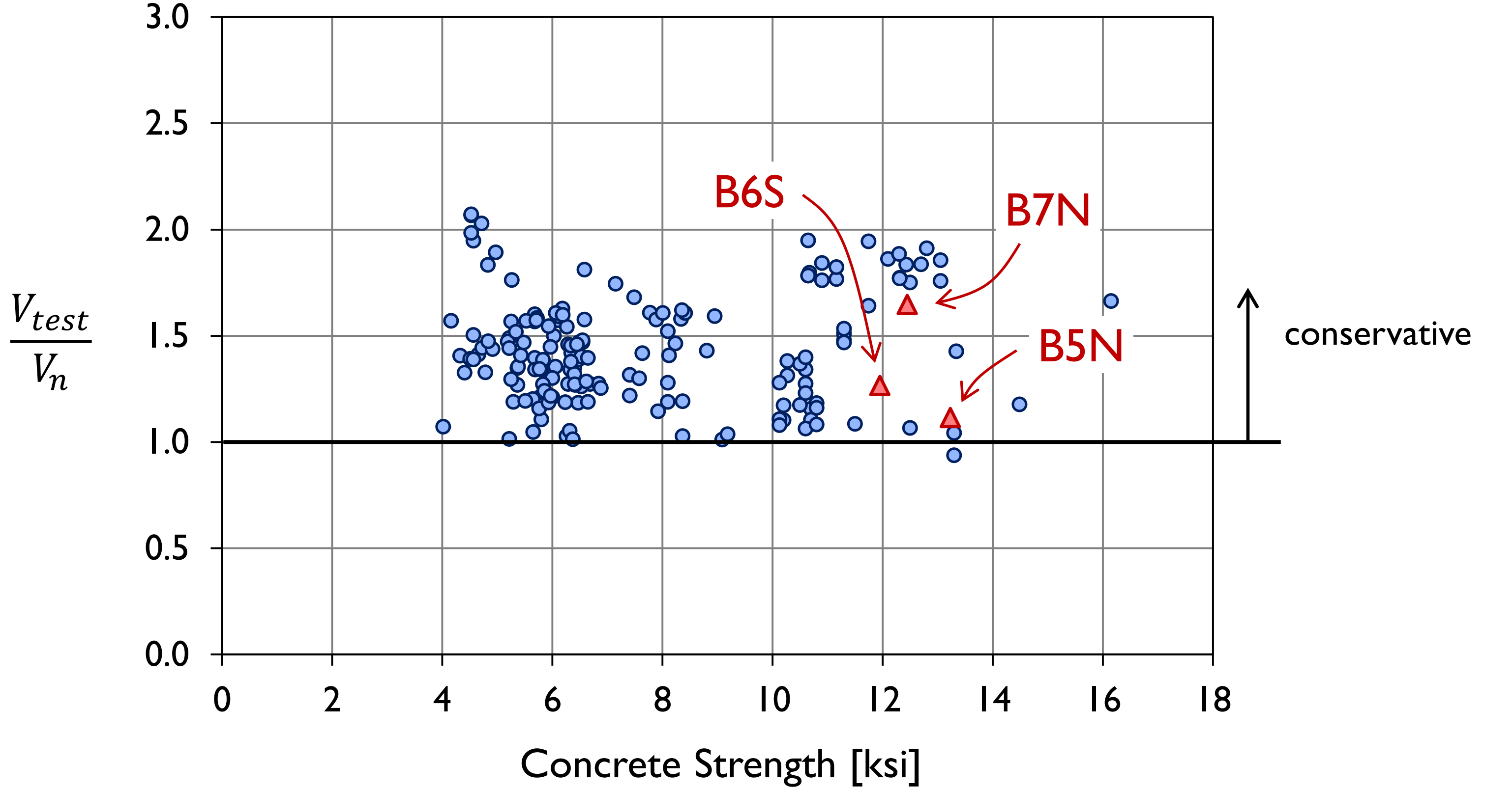
Flexure-Shear Failure

Comparison to the Literature



V_n calculated using AASHTO
LRFD General Procedure (2010)

Comparison to the Literature



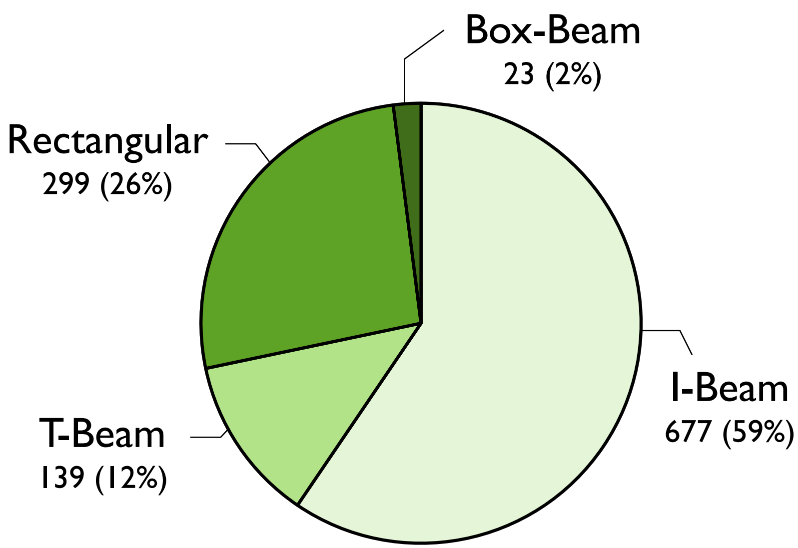
V_n calculated using AASHTO
LRFD General Procedure (2010)

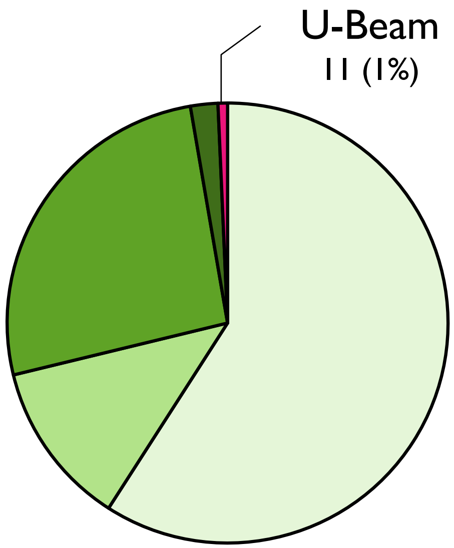
Bridging the Gap

[or, Filling Holes in the Literature]

New Data in Literature

- Shear Test Program

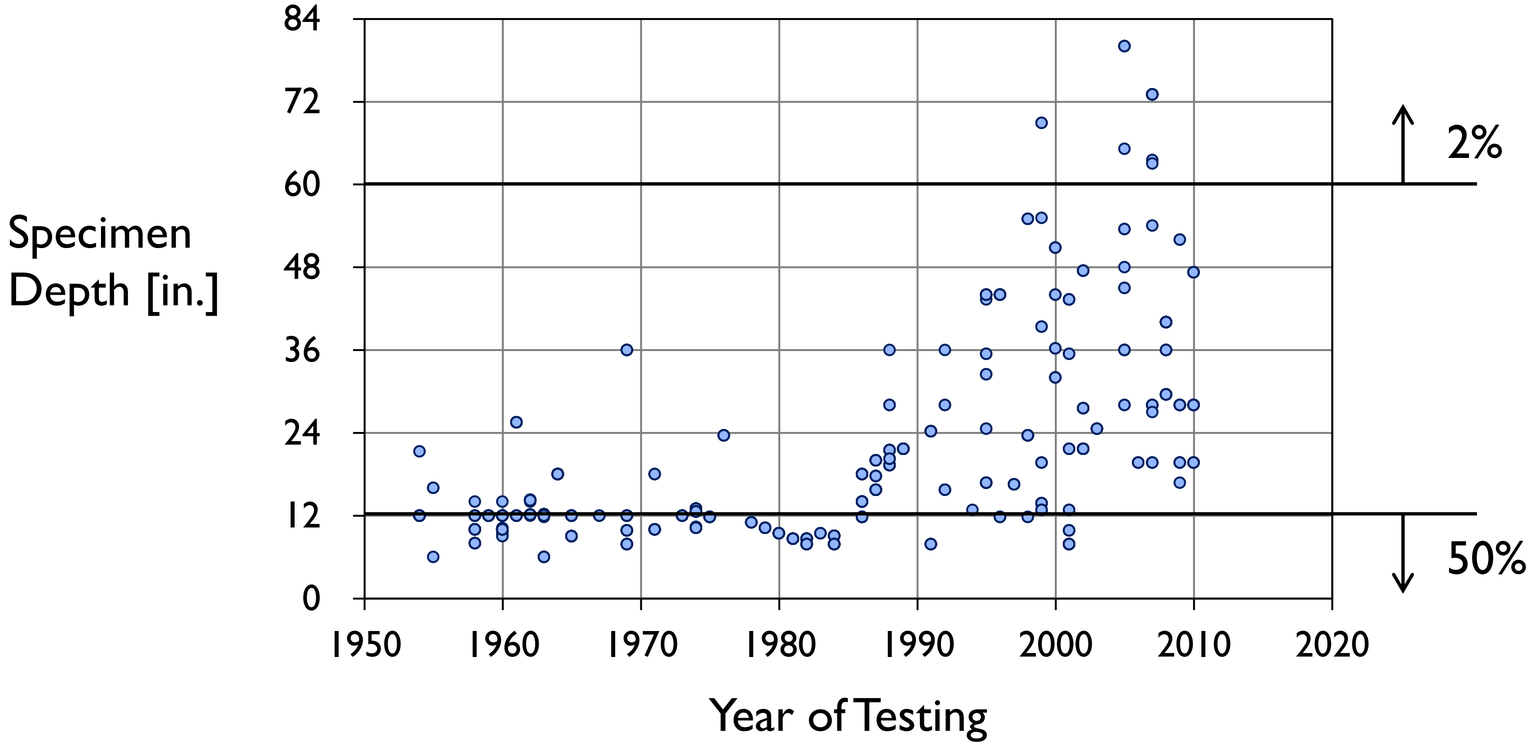




[data from UTPCSDB Filtered Database, N = 1138]

New Data in Literature

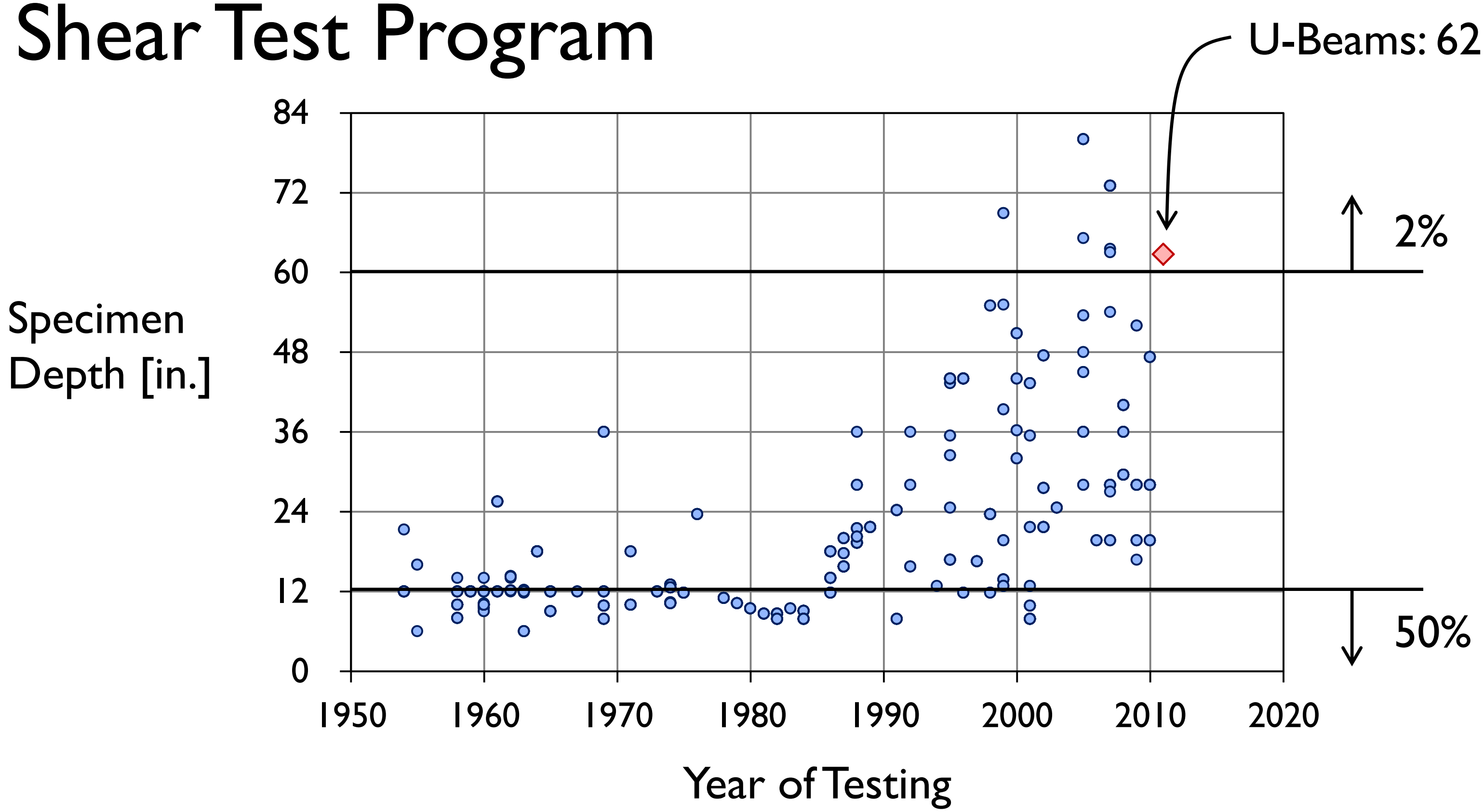
- Shear Test Program



[data from UTPCSDB Filtered Database, N = 1138]

New Data in Literature

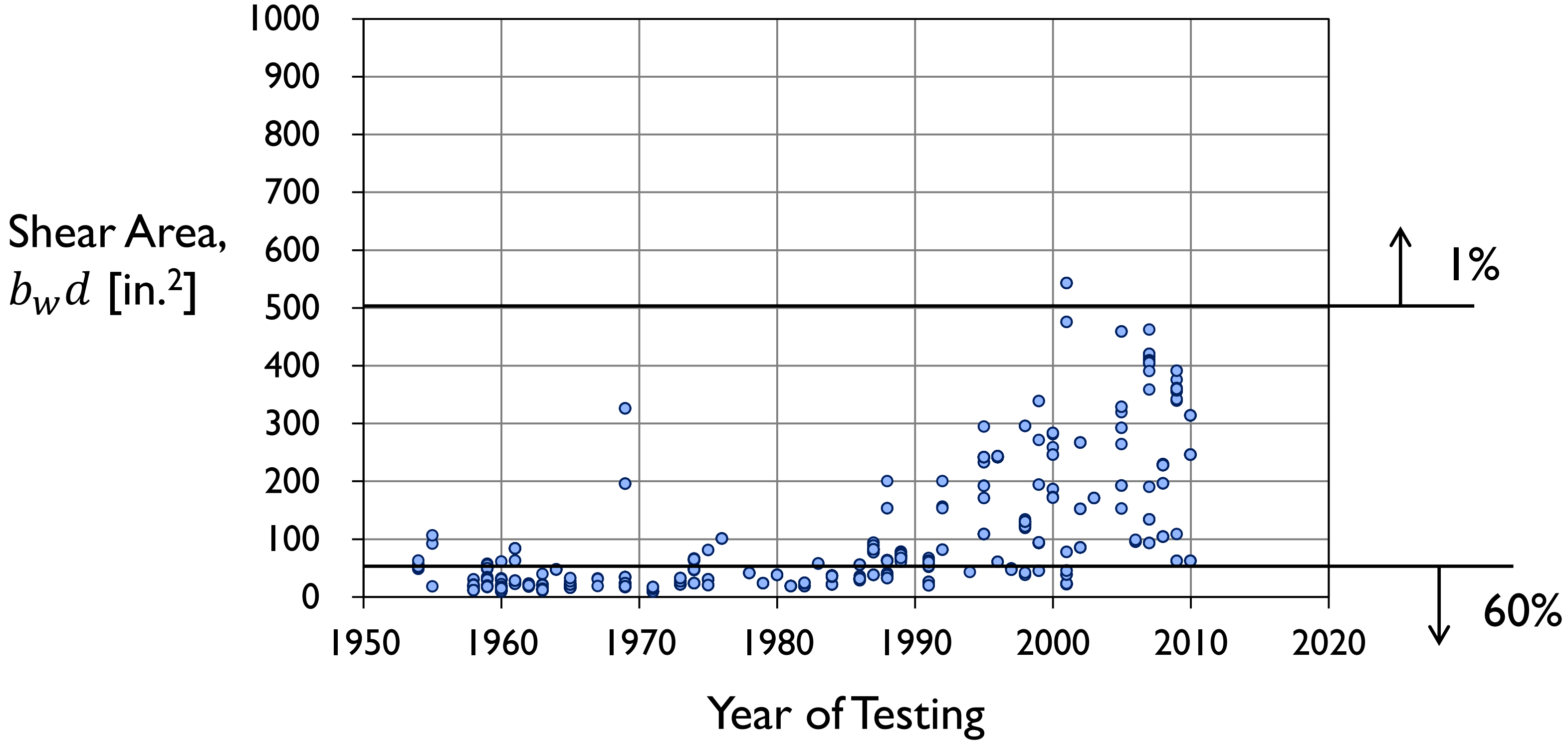
- Shear Test Program



[data from UTPCSDB Filtered Database, N = 1138]

New Data in Literature

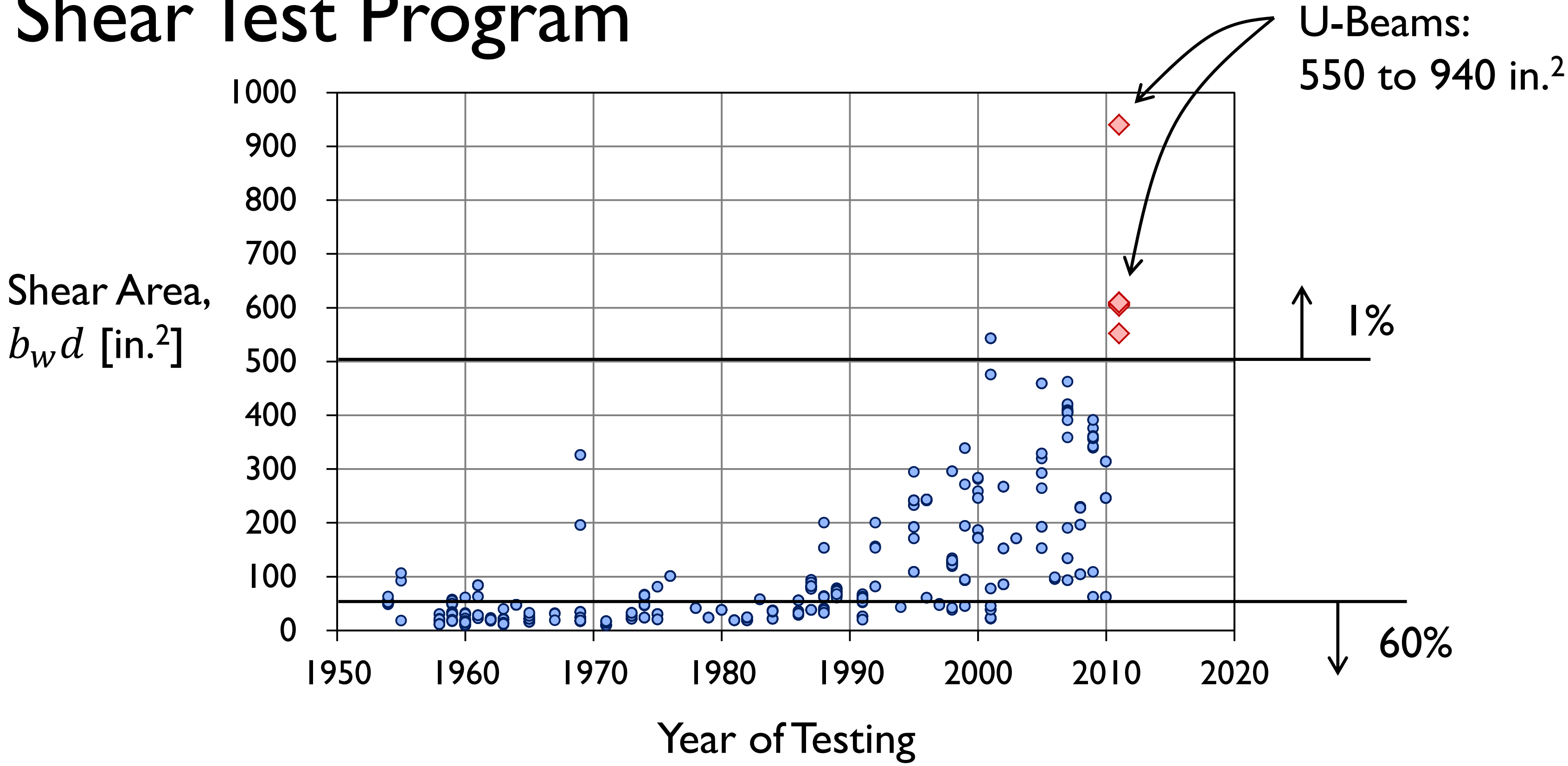
- Shear Test Program



[data from UTPCSDB Filtered Database, N = 1138]

New Data in Literature

- Shear Test Program

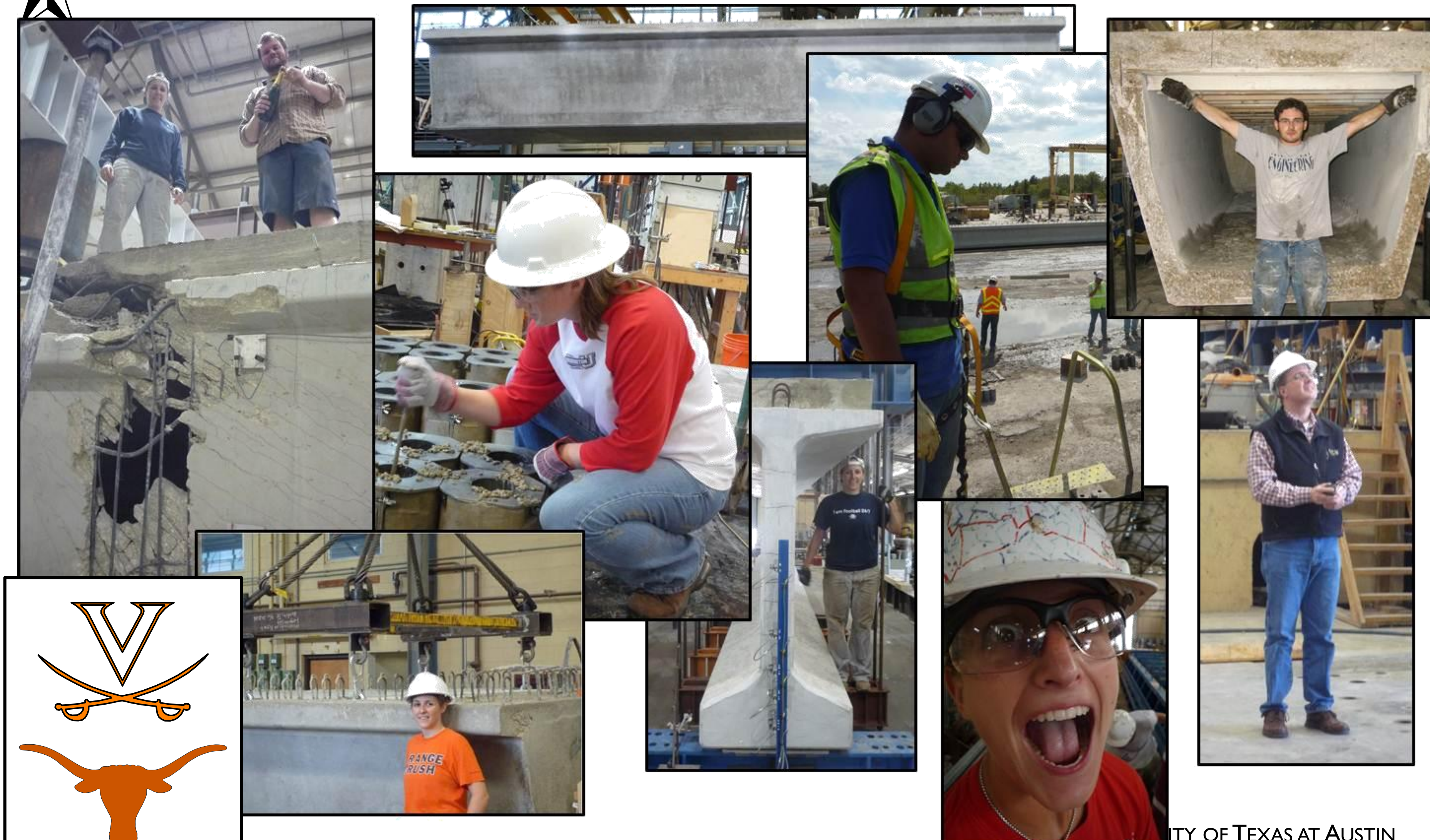


[data from UTPCSDB Filtered Database, N = 1138]

Conclusions & Advice

- Research is a fluid, cyclic process; the original question asked may become unimportant by the end
- Don’t be afraid to think outside the box – just because something “should be” doesn’t mean it “is”
- Equations learned in class were developed somewhere, verified somehow; it’s nice to know where and how
- Getting involved, hands-on, is the best way to understand how something works

Questions or Comments?

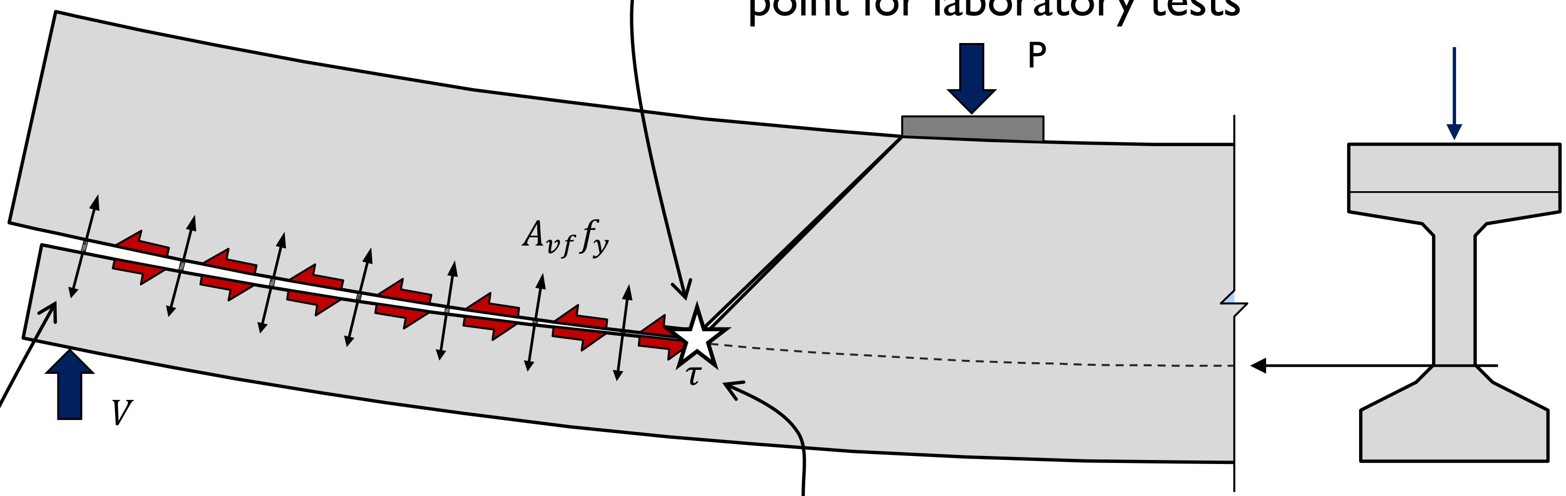


SHEAR STRENGTH:

Horizontal Shear in Prestressed Beams

Horizontal Shear in Prestressed Beams

To verify method, compared demand to capacity at a single point for laboratory tests



Calculate capacity following shear-friction theory, giving credit to cohesion between concrete sections and clamping force from reinforcement

Find horizontal stress on interface and use it to calculate demand

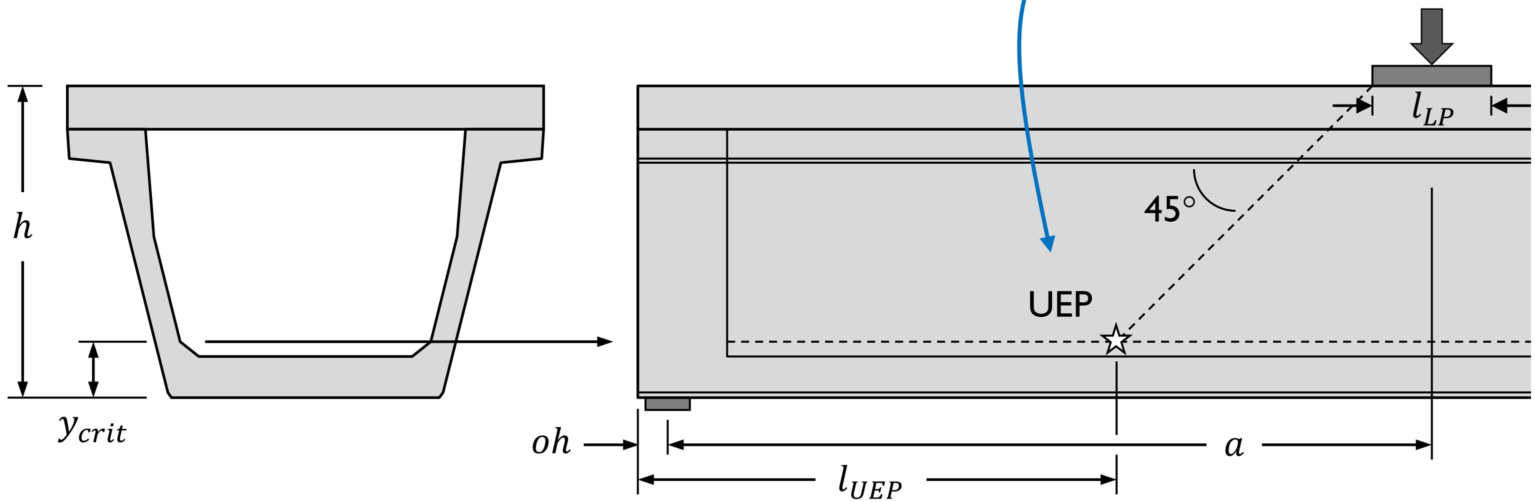
Calculation Method

Horizontal Shear Demand:

$$V_{u_{hs}} = v_{hs} b_w (l_{UEP} - oh)$$

average horizontal shear stress

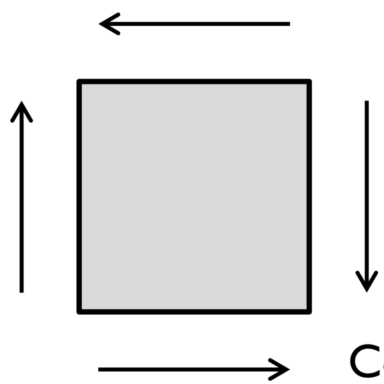
distance from centerline of bearing pad to the ultimate evaluation point



Calculation Method

Definition of average horizontal shear stress:

$$v_{hs} = v_{avg} = \frac{V}{b_w d} = \tau$$



Complementary property of shear

Non-linear analyses showed that average stress was a reasonable approximation of the stress at the critical interface

Calculation Method

Horizontal Shear Capacity:

$$V_{ni} = k_d\left[cA_{cv} + \mu\left(A_{vf}f_y - 0.04P_{PS}\right)\right]$$

concrete cohesion term

steel friction / clamping term

prestress transfer penalty

beam shape / reinforcement detailing factor

Calculation Method

Horizontal Shear Capacity:

$$V_{ni} = k_d\left[cA_{cv} + \mu\left(A_{vf}f_y - 0.04P_{PS}\right)\right]$$

AASHTO shear friction equation

Calculation Method

Horizontal Shear Capacity:

$$V_{ni} = k_d\left[cA_{cv} + \mu\left(A_{vf} f_y - \underbrace{0.04P_{PS}}_{\text{prestress transfer penalty}}\right)\right]$$

Bars near beam end are stressed at prestress transfer, to resist a force equal to 4% of P_{PS}

Calculation Method

Horizontal Shear Capacity:

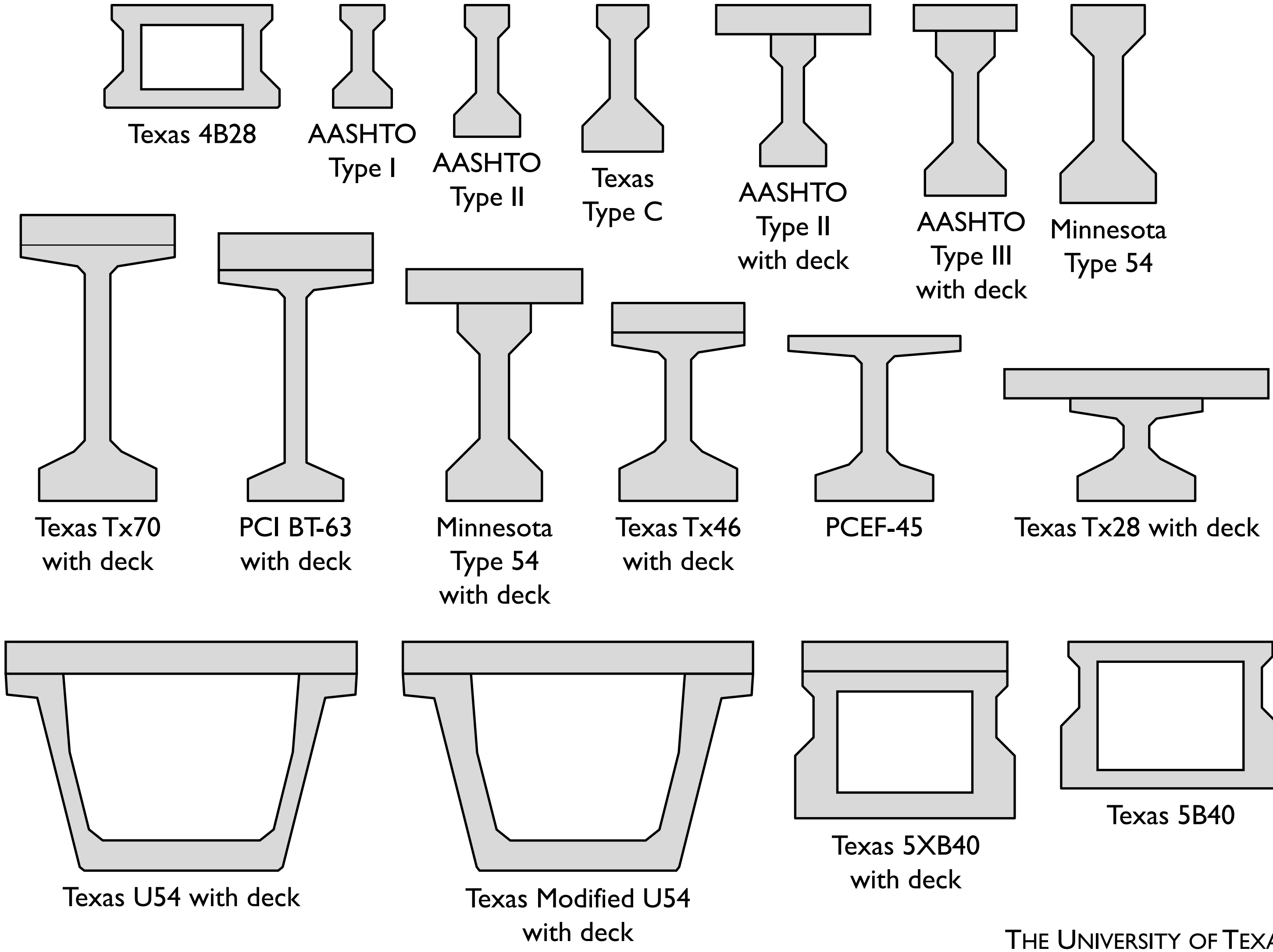
$$V_{ni} = k_d\left[cA_{cv} + \mu\left(A_{vf}f_y - 0.04P_{PS}\right)\right]$$

beam shape / reinforcement detailing factor

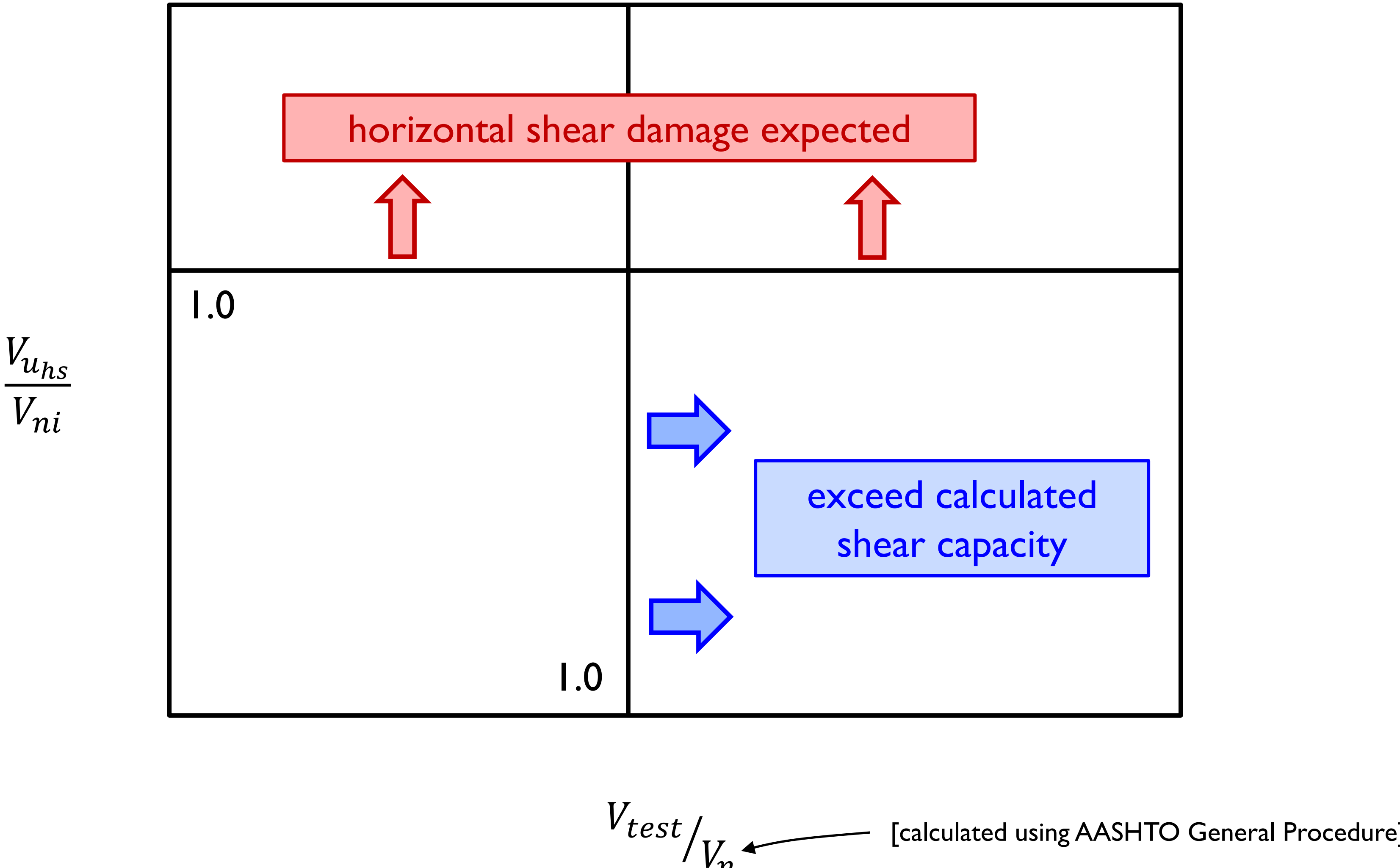
Horizontal Shear Evaluation Database

- Subset of UTPCSDB Evaluation-Level I Database
- Specimens removed if:
  - » post-tensioned
  - » rectangular or T-shaped
  - » non-standard beam section
  - » skewed beam
  - » insufficient reinforcement information available
- HSED contains 69 data points (including 8 U-Beams)

Horizontal Shear Evaluation Database

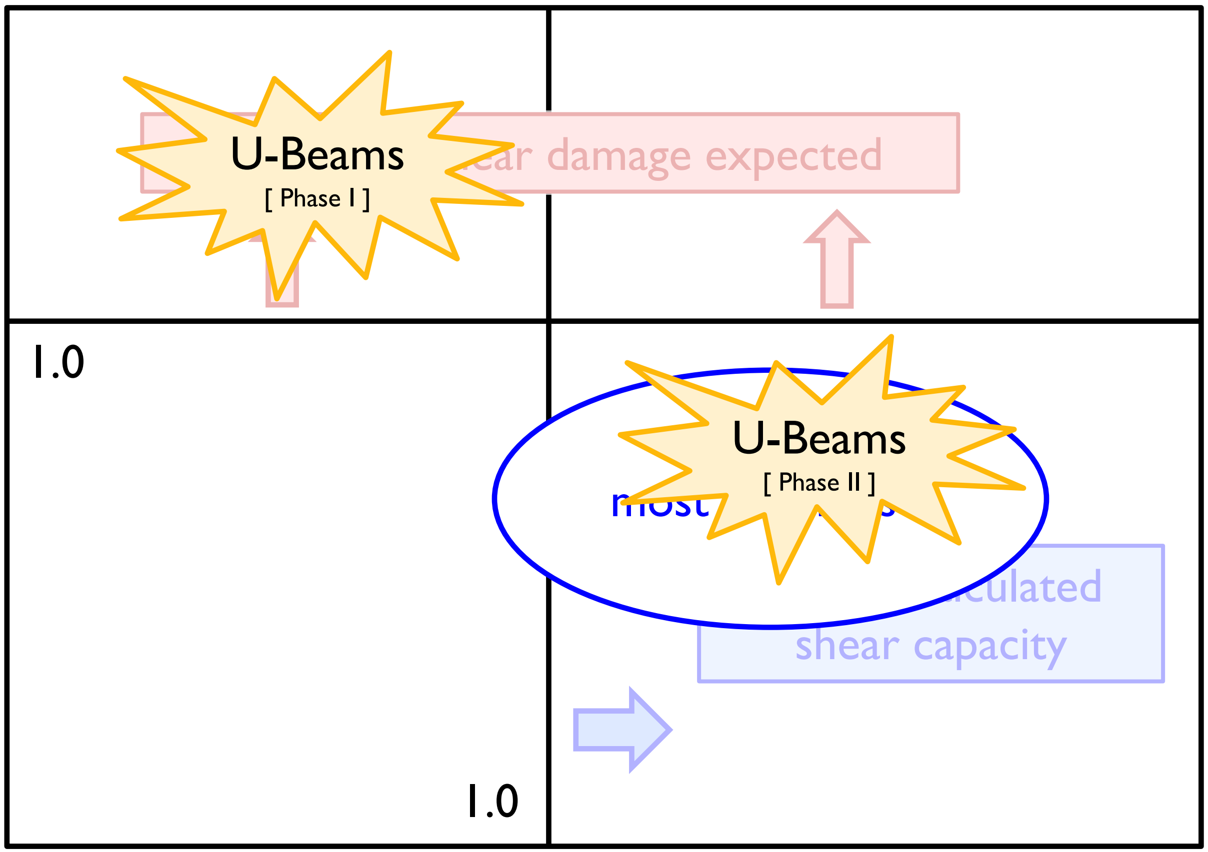


Horizontal Shear Evaluation



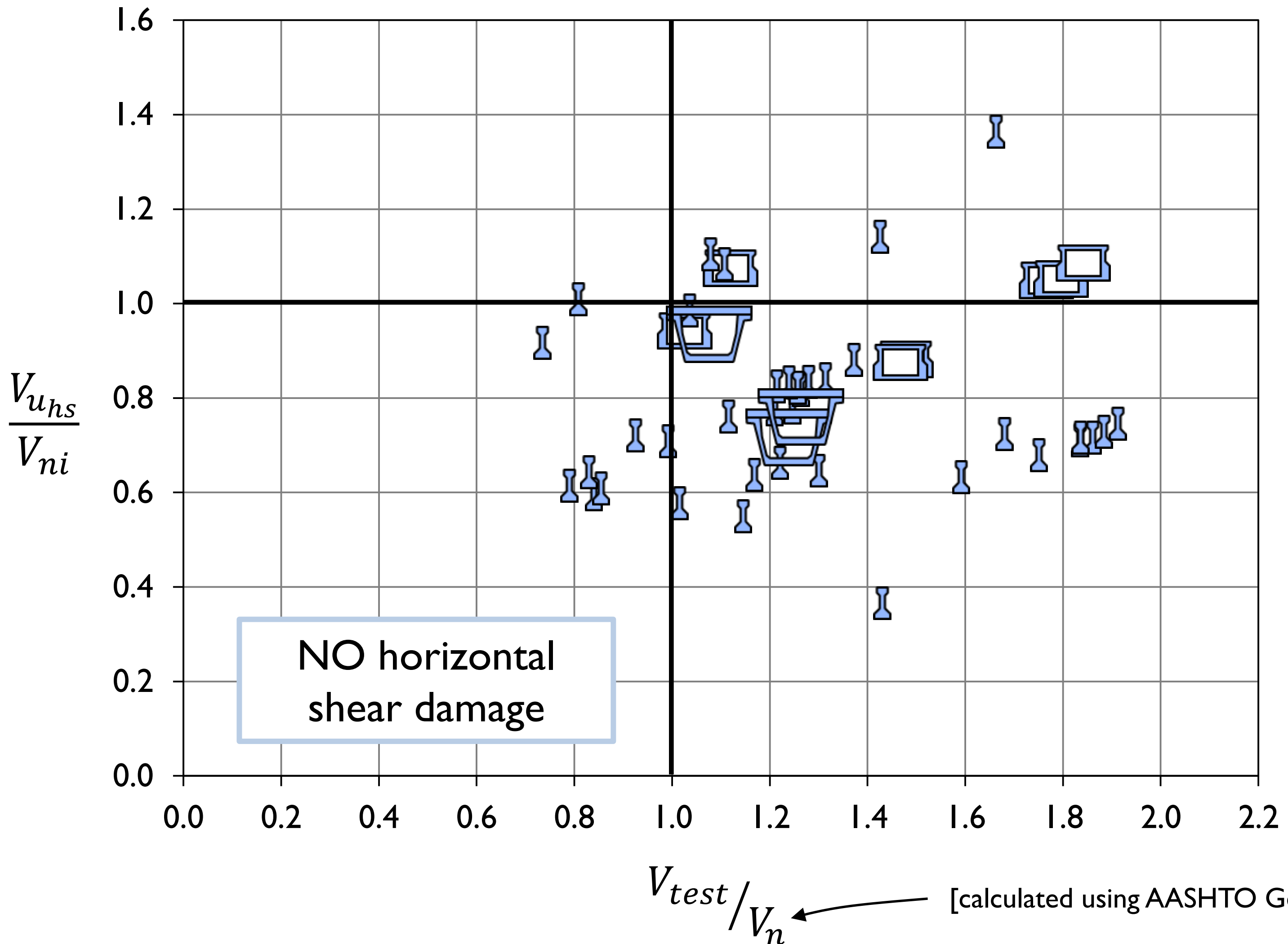
Horizontal Shear Evaluation

$\frac{V_{u_{hs}}}{V_{ni}}$



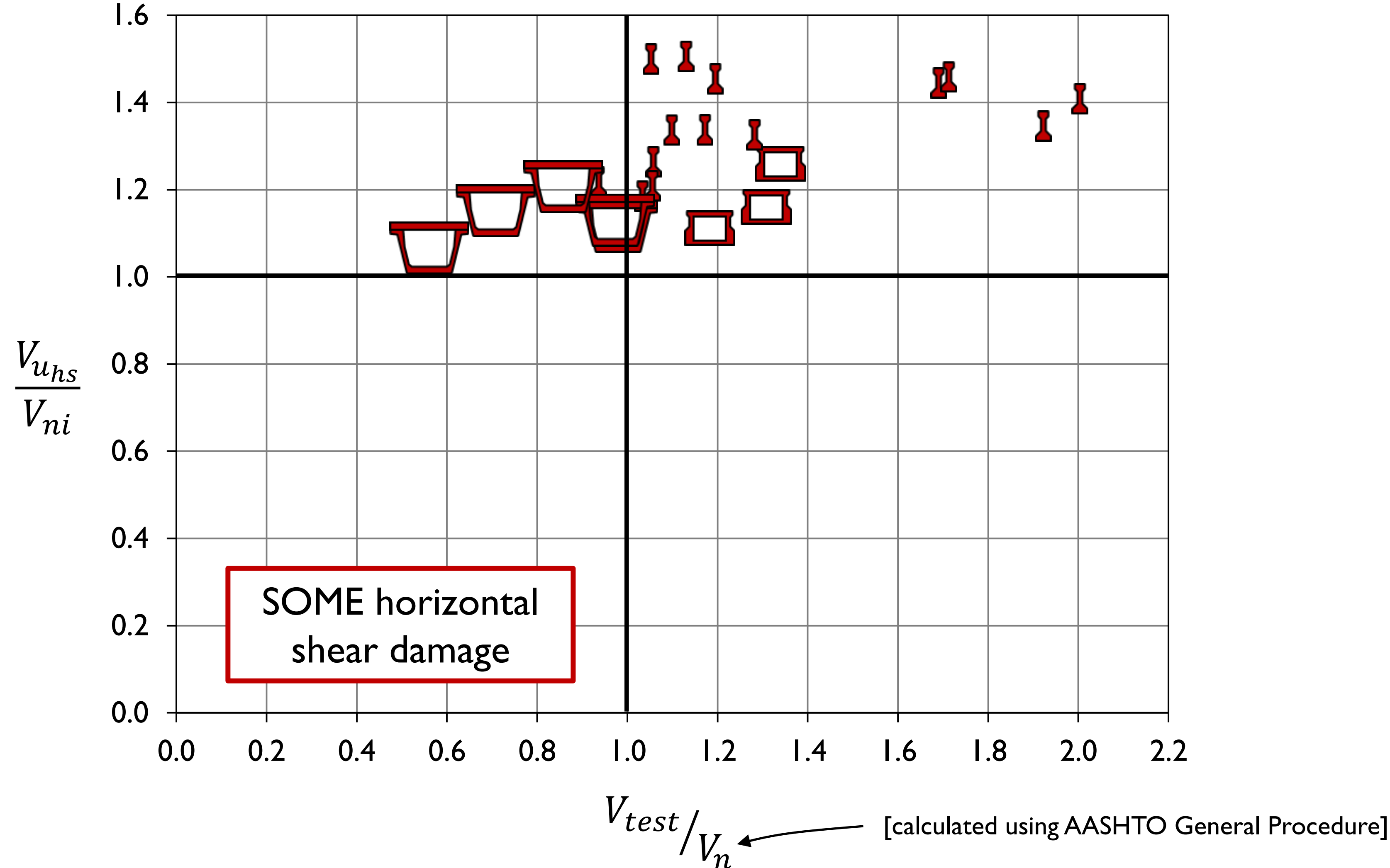
V_{test}/V_n ← [calculated using AASHTO General Procedure]

Horizontal Shear Evaluation

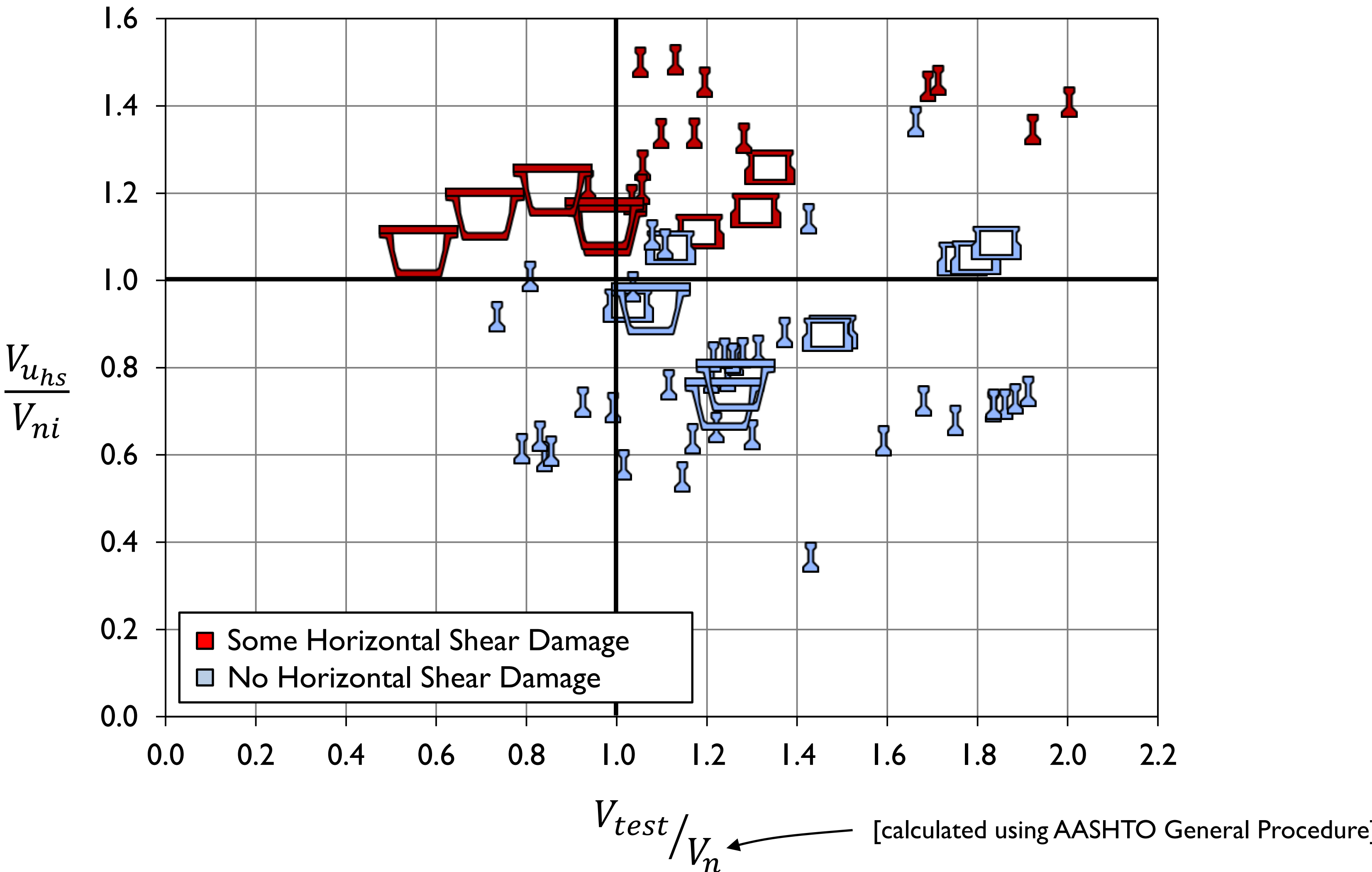


[calculated using AASHTO General Procedure]

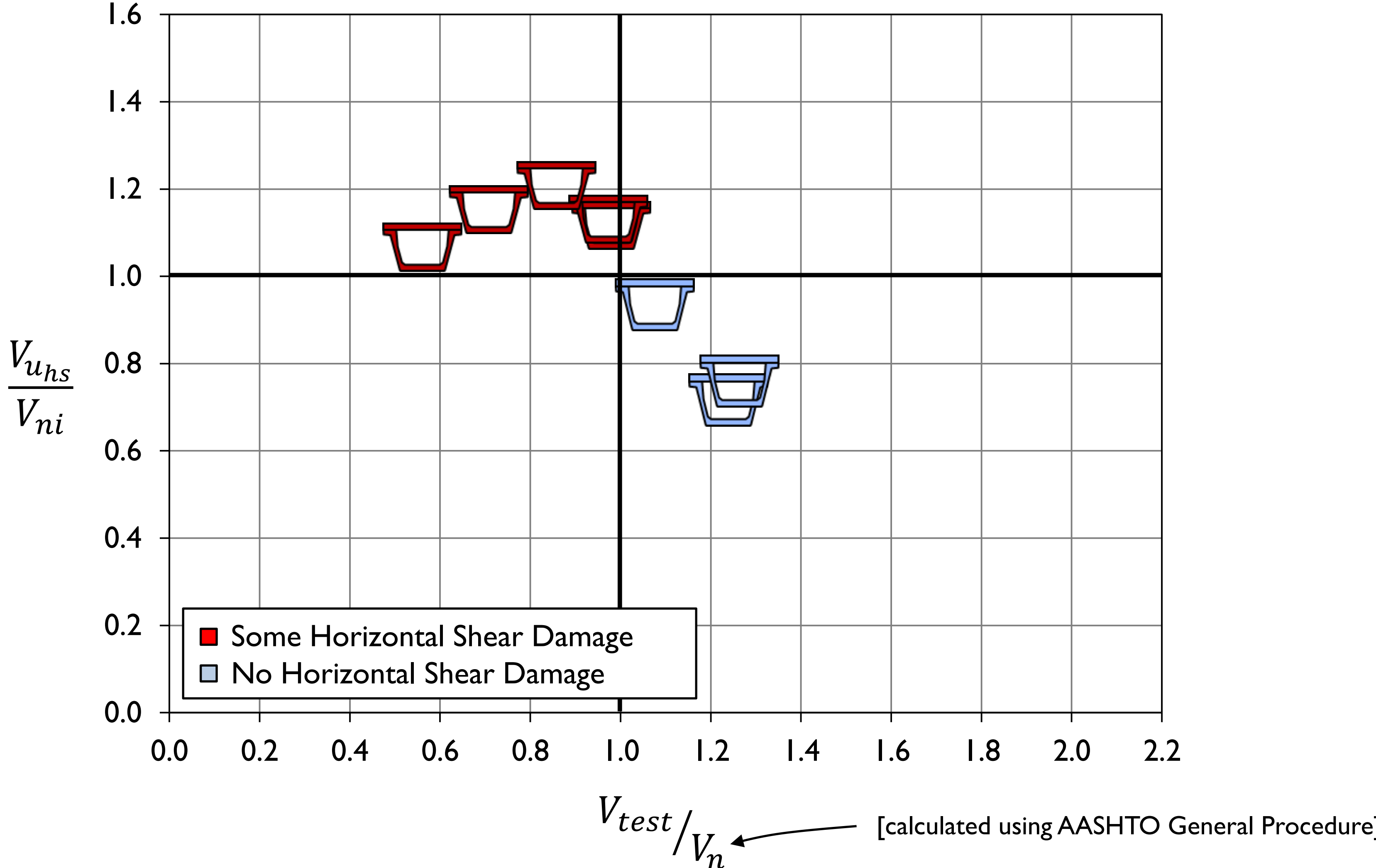
Horizontal Shear Evaluation



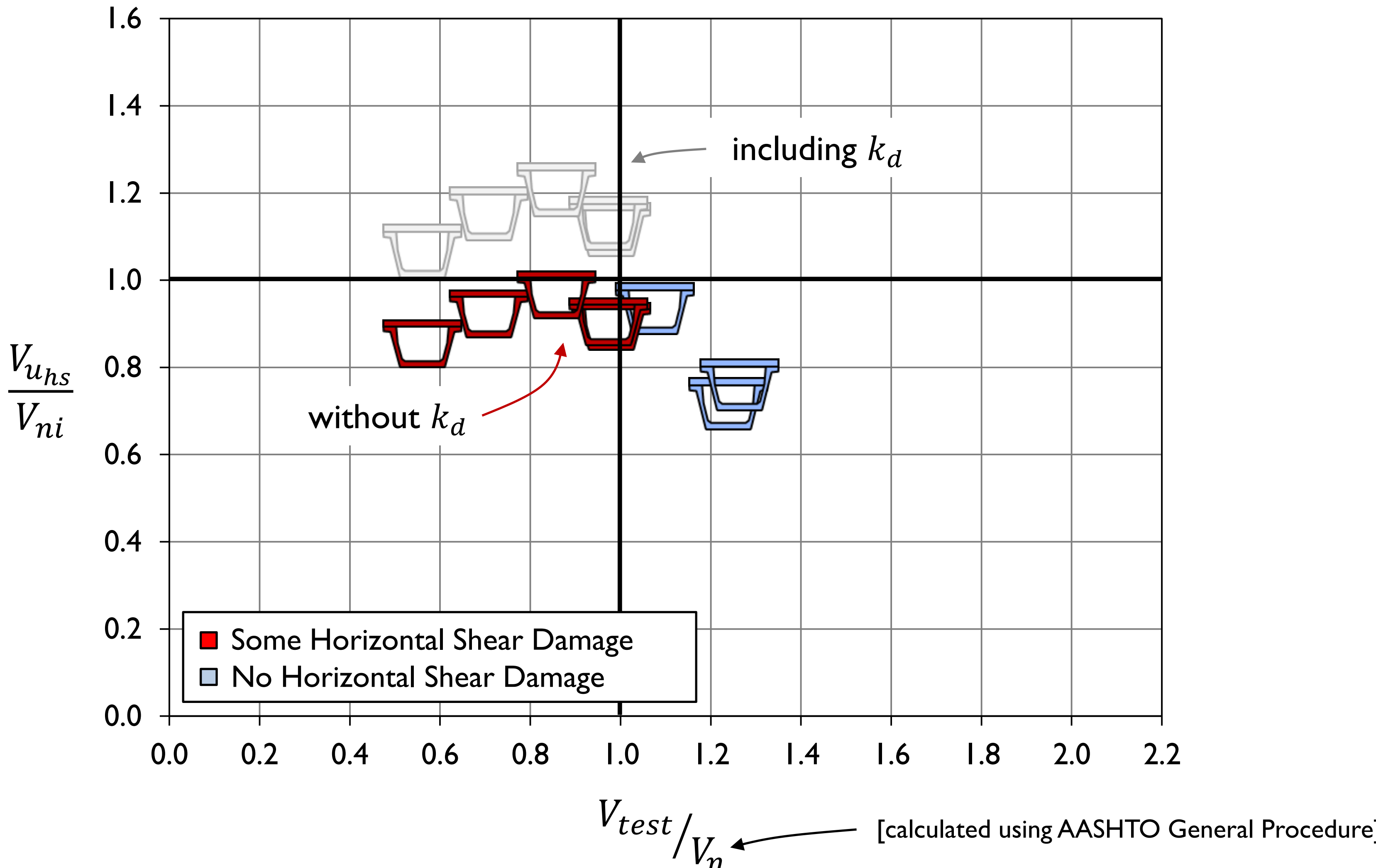
Horizontal Shear Evaluation



Horizontal Shear in U-Beams



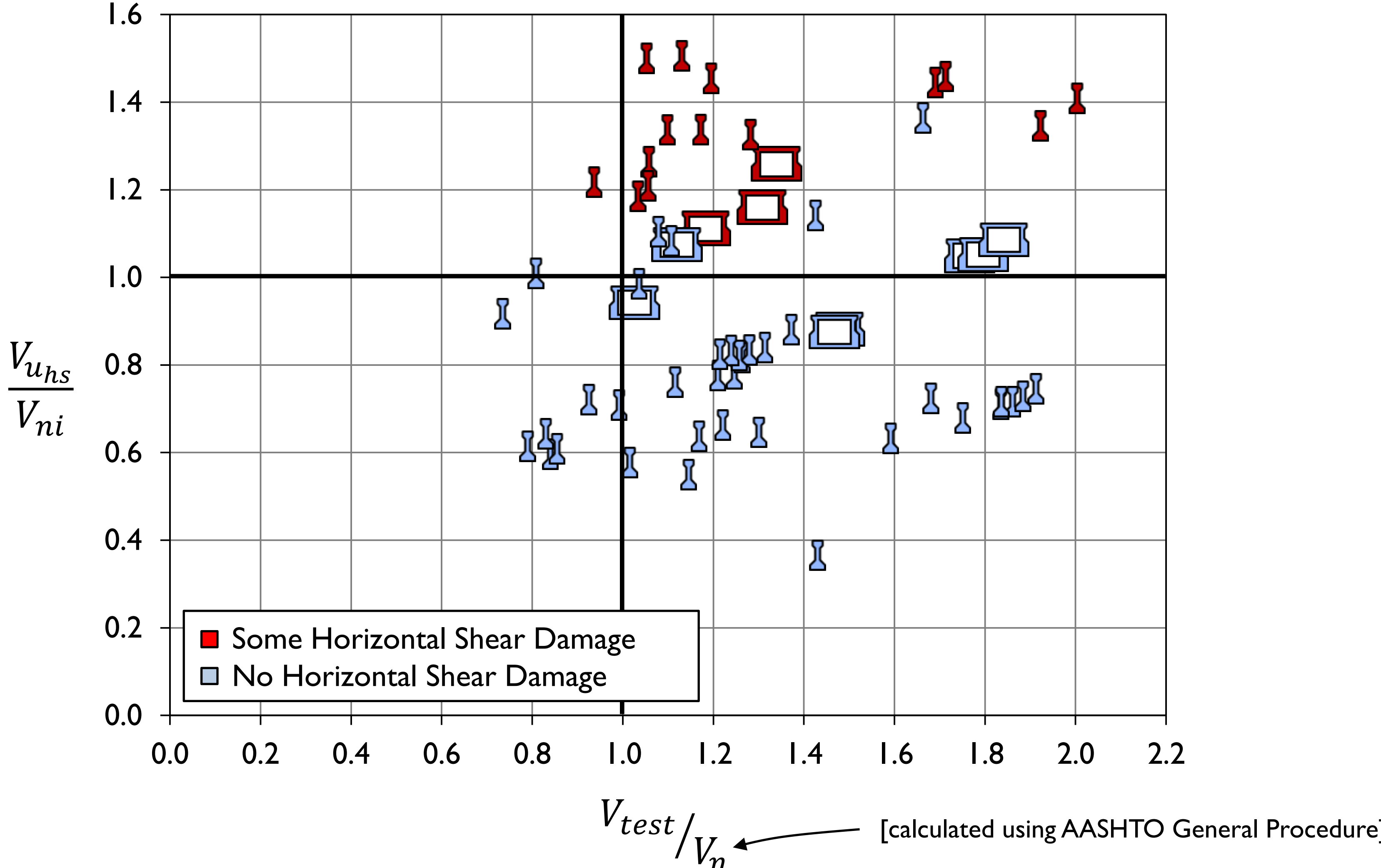
Horizontal Shear in U-Beams



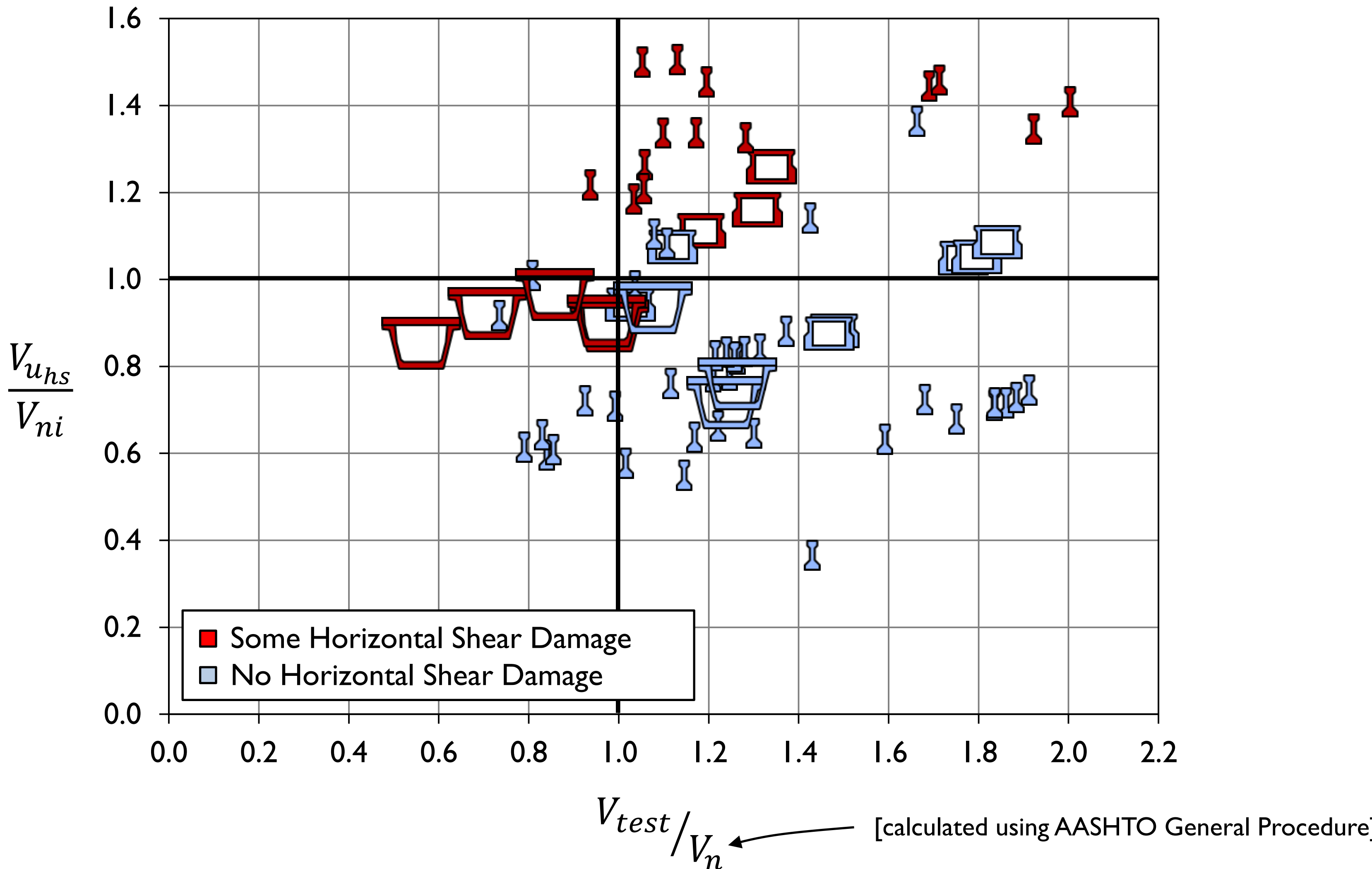
Horizontal Shear in U-Beams

What is k_d and where did it come from?

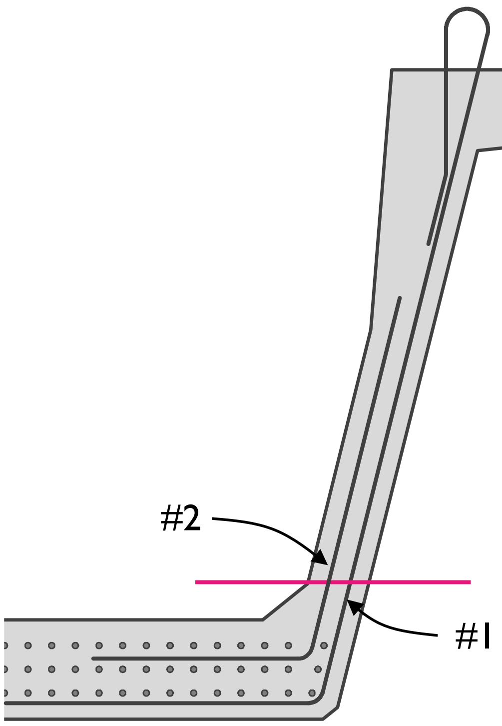
HSED without U-Beams

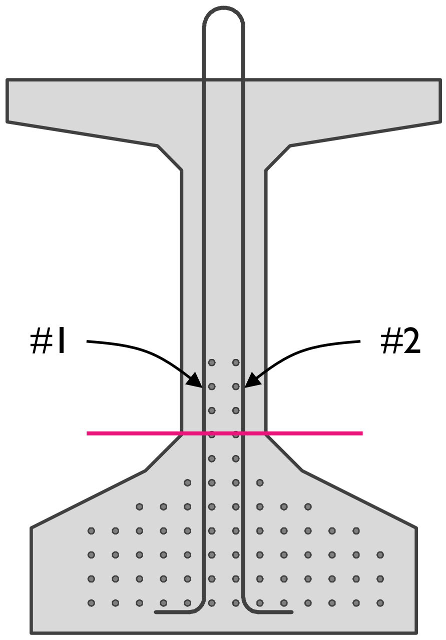


HSED with U-Beams

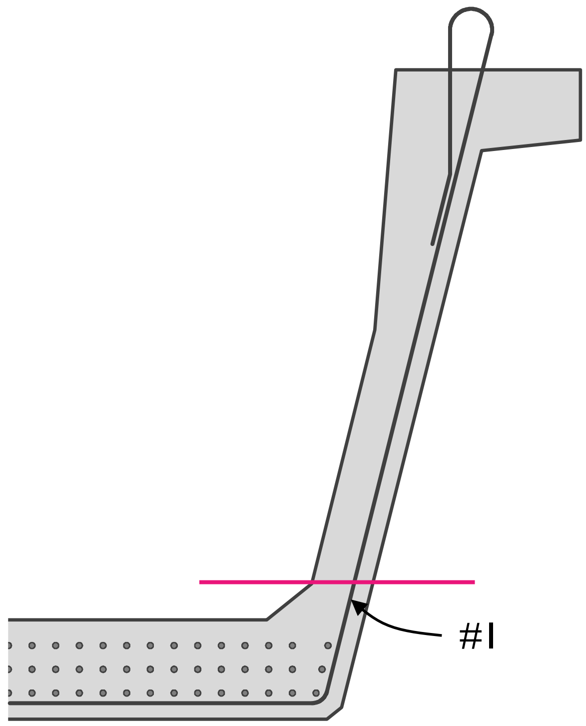


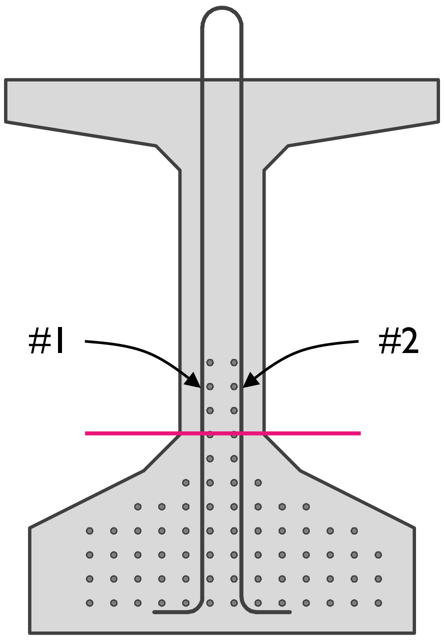
Horizontal Shear in U-Beams



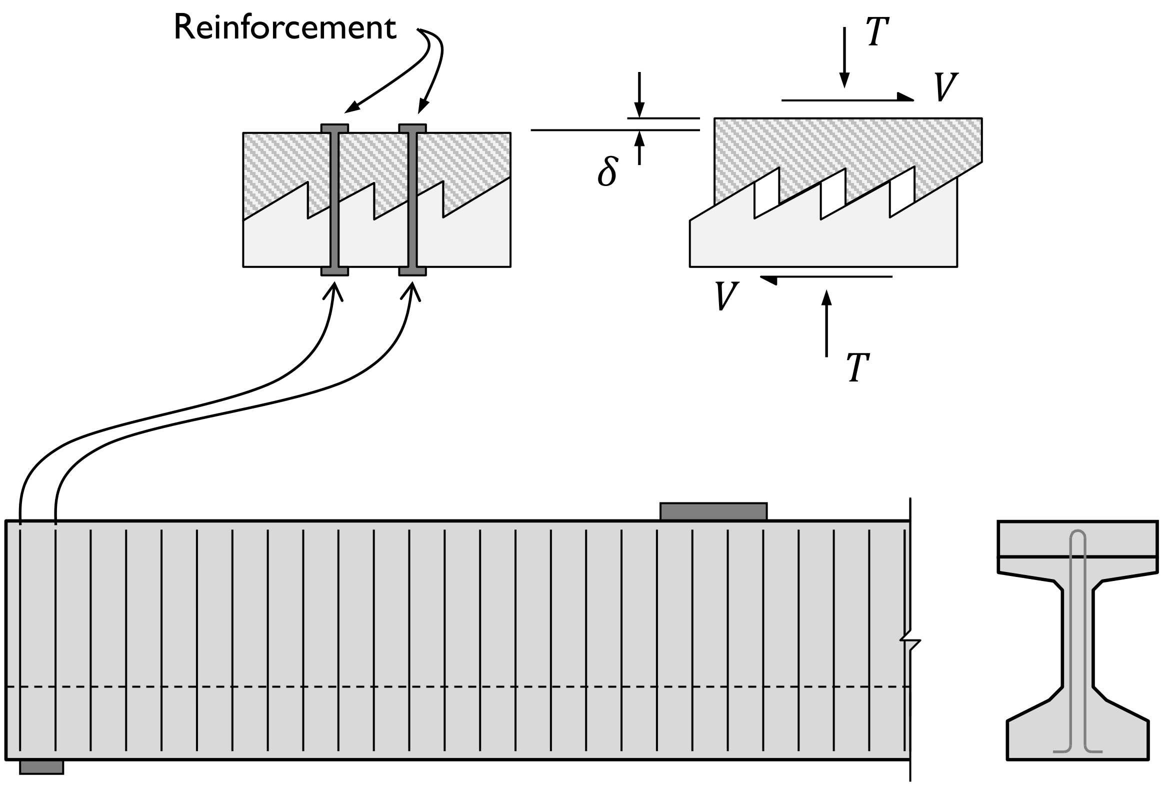


Horizontal Shear in U-Beams

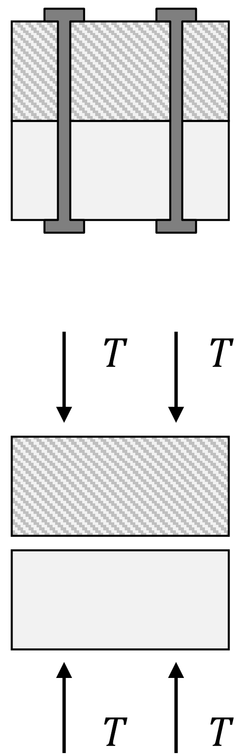




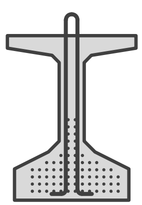
Shear Friction

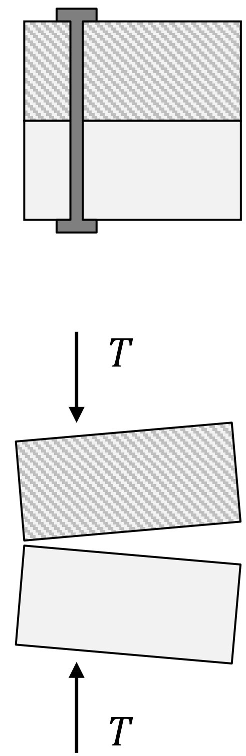


Shear Friction

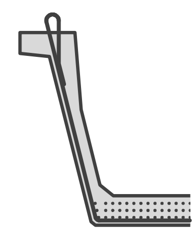


Side view of theoretical shear friction specimen with distributed reinforcement

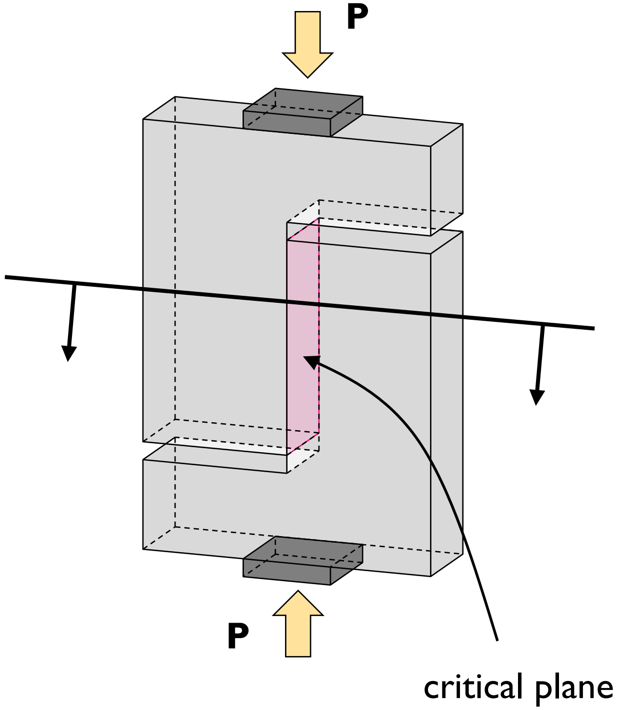


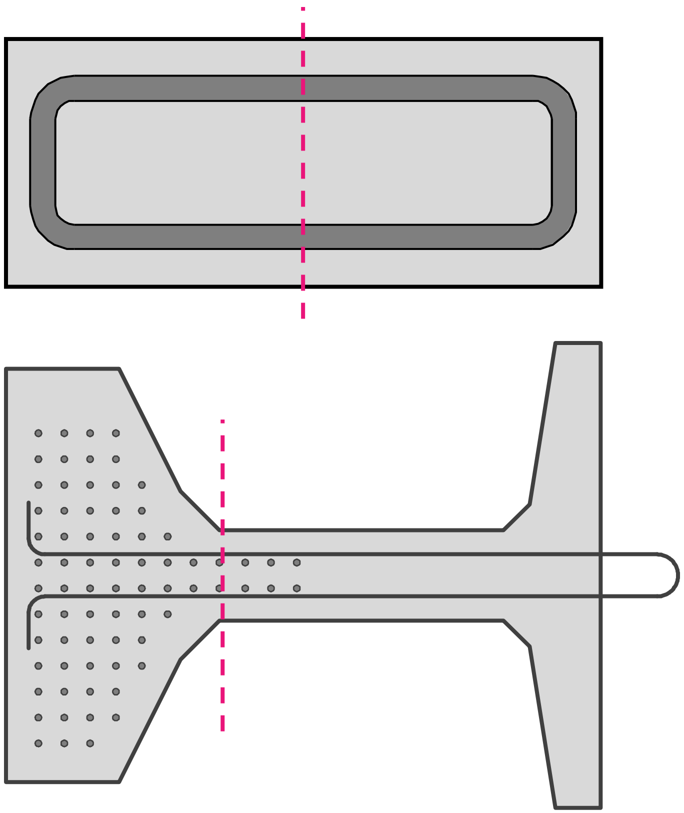


Side view of theoretical shear friction specimen with asymmetrical reinforcement

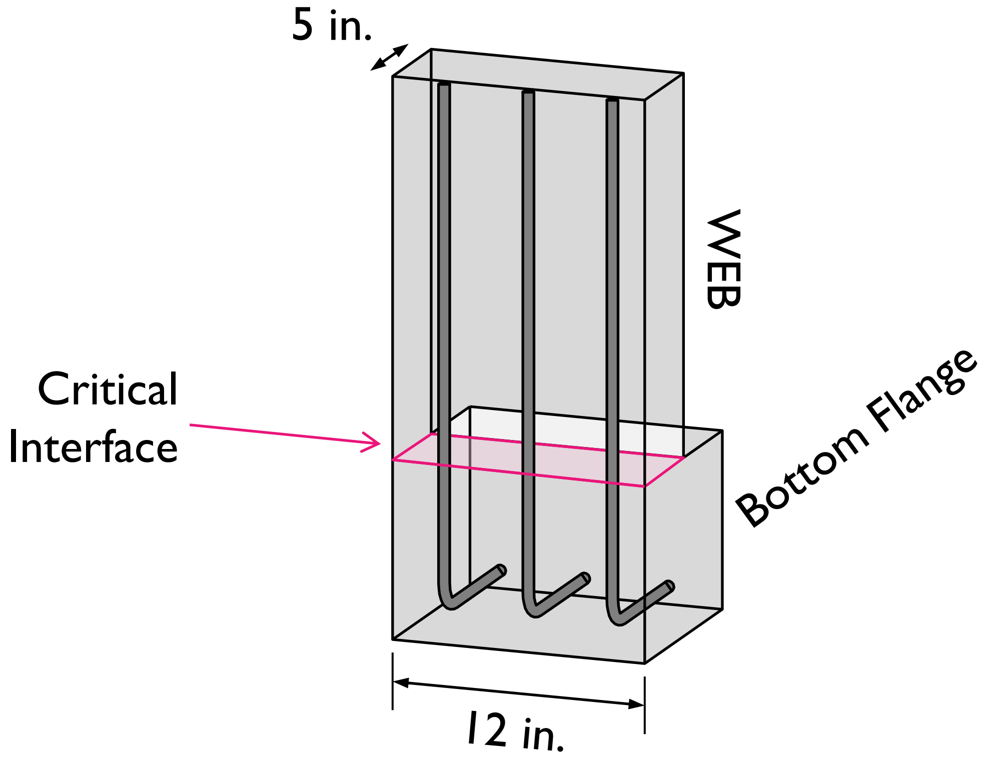


Horizontal Shear in U-Beams

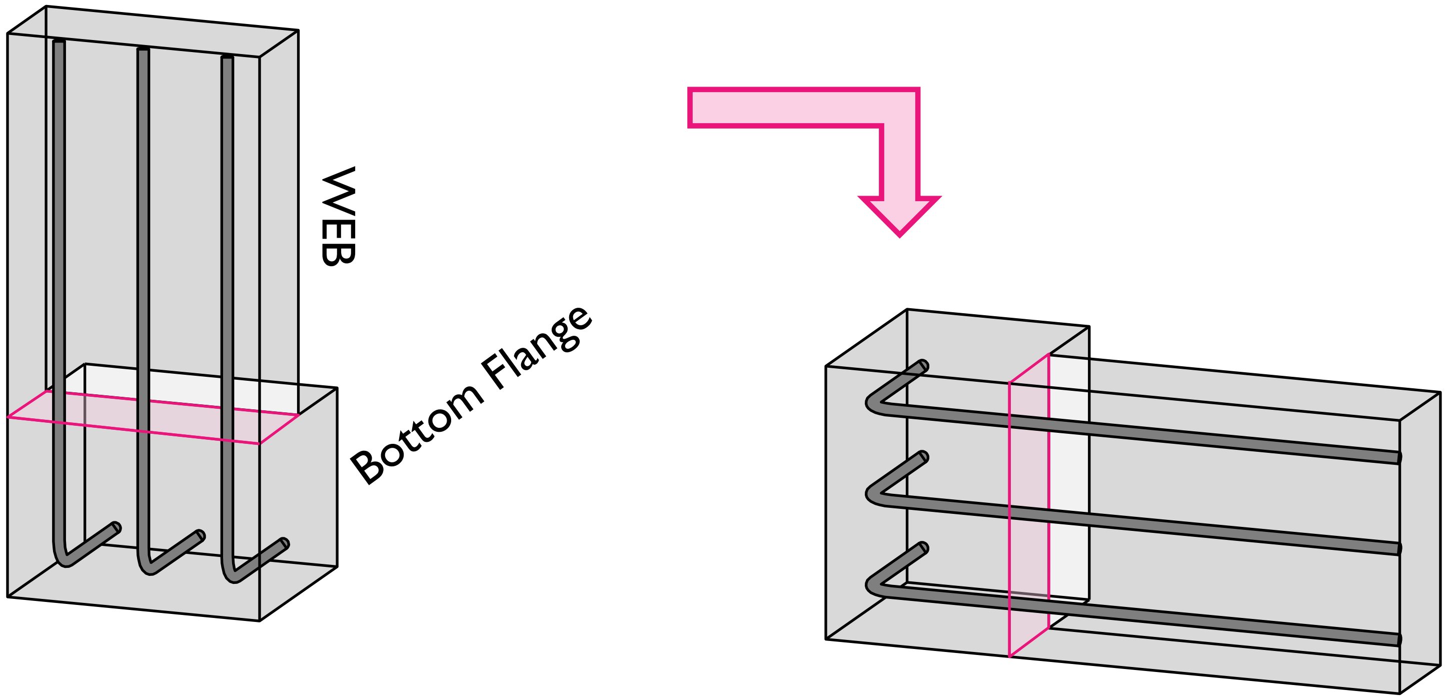




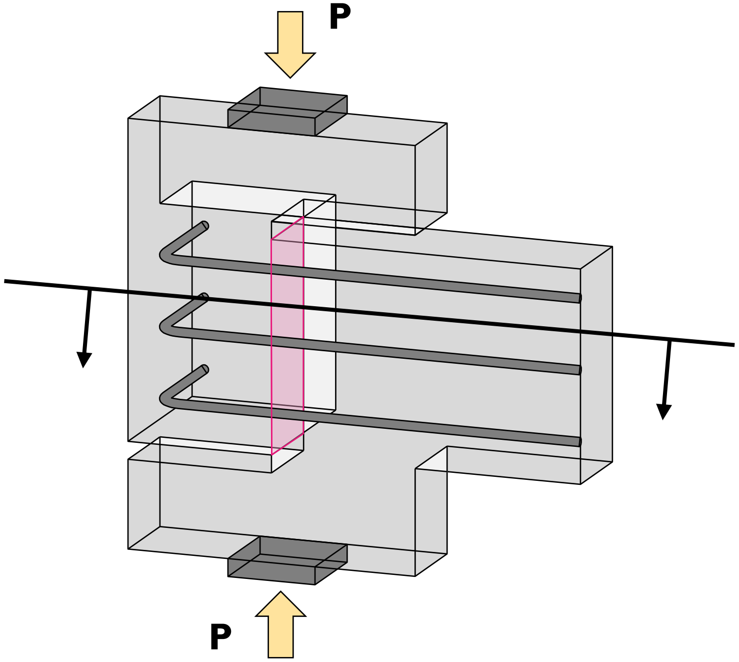
Horizontal Shear in U-Beams

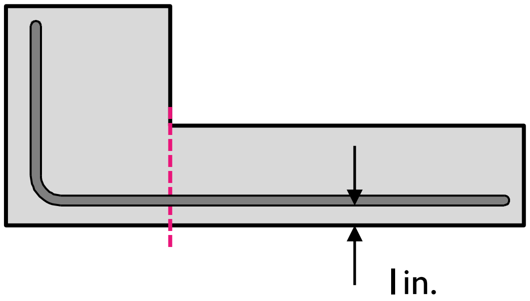


Horizontal Shear in U-Beams

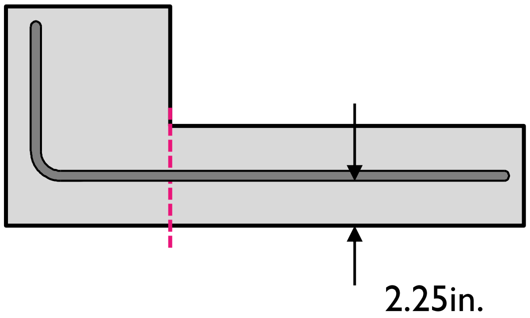


Horizontal Shear in U-Beams



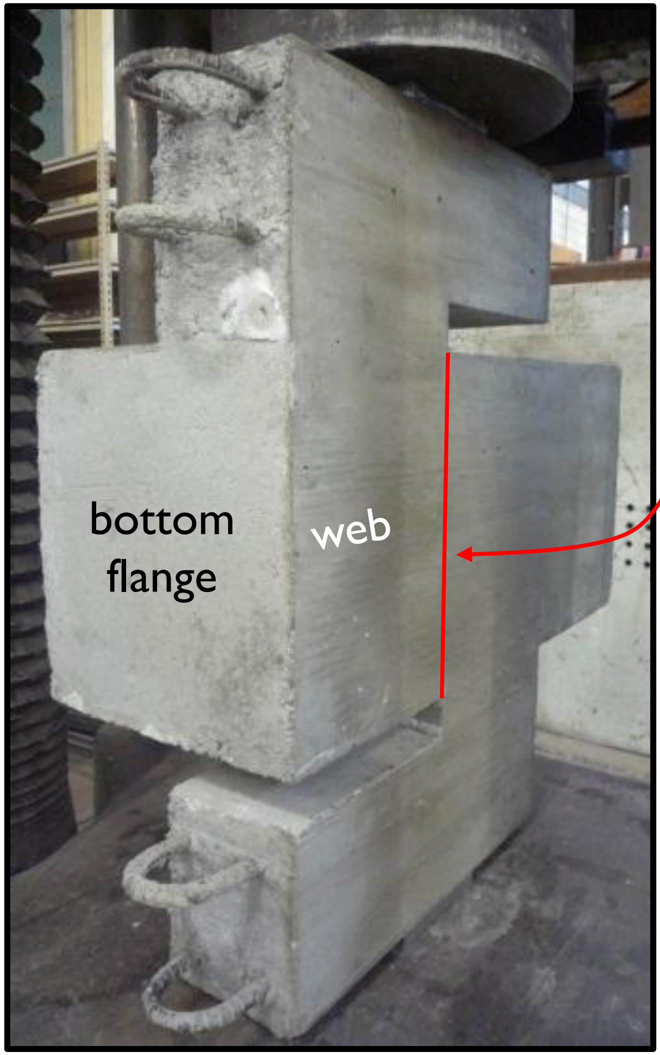


OFFSET BAR SPECIMEN



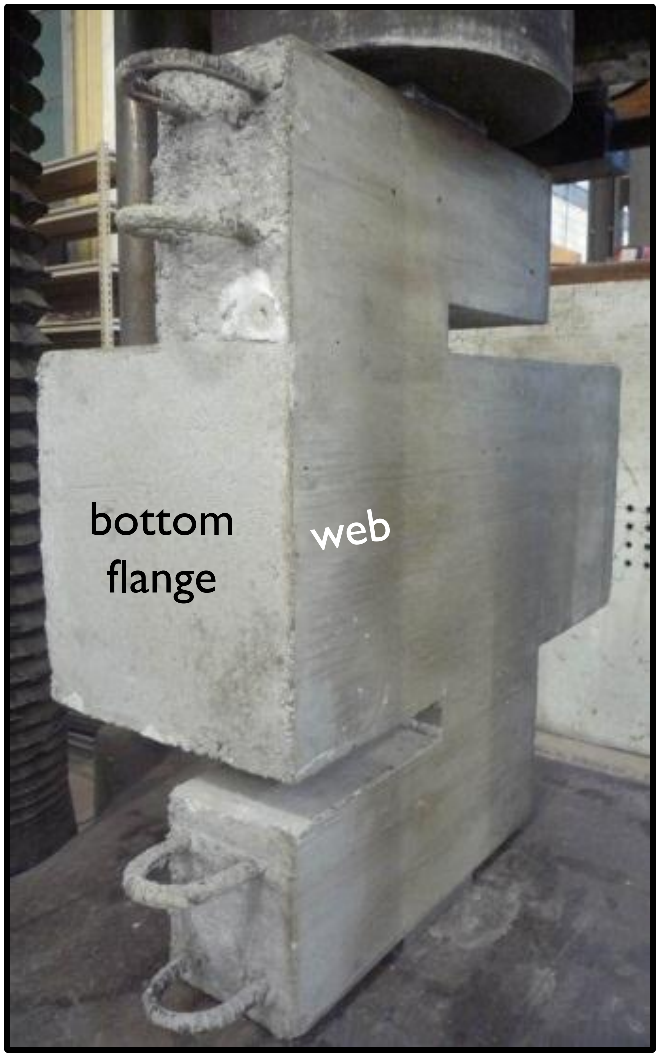
CENTERED BAR SPECIMEN

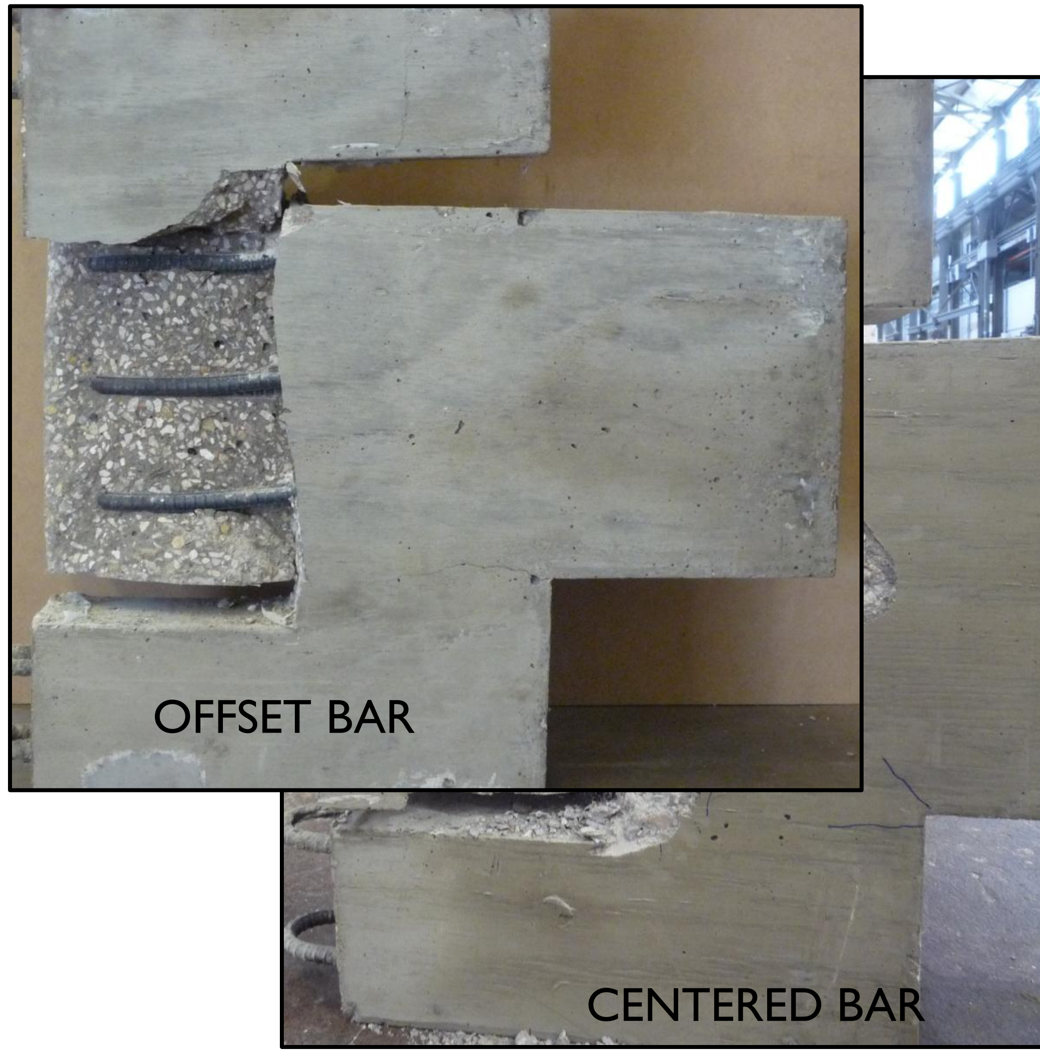
Horizontal Shear in U-Beams



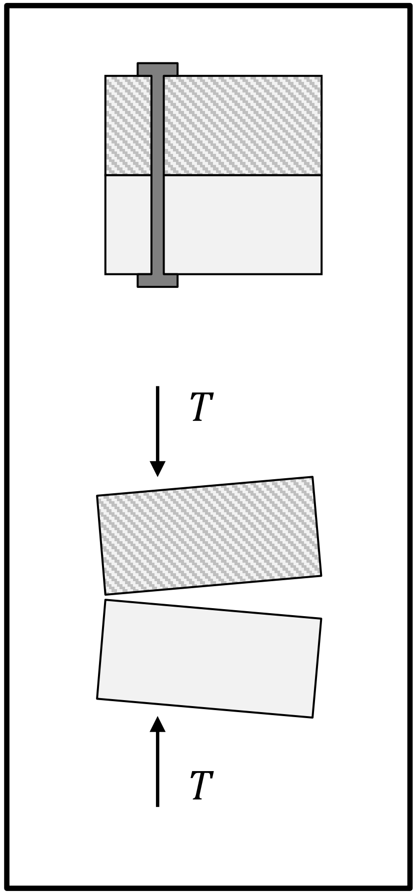
critical interface

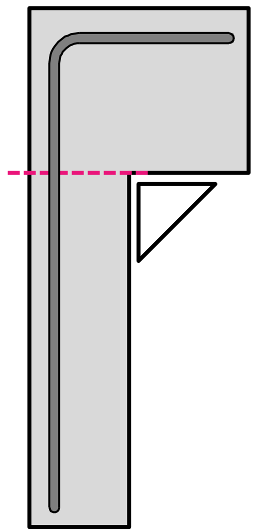
Horizontal Shear in U-Beams





Horizontal Shear in U-Beams





Modified Push-Off Results

Calculated capacity = 74.4 kip

		Centered	Offset
Series 1	Measured Value	67.4 kip	54.7 kip
Series 2	Measured Value	73.2 kip	60.1 kip

Modified Push-Off Results

Calculated capacity = 74.4 kip

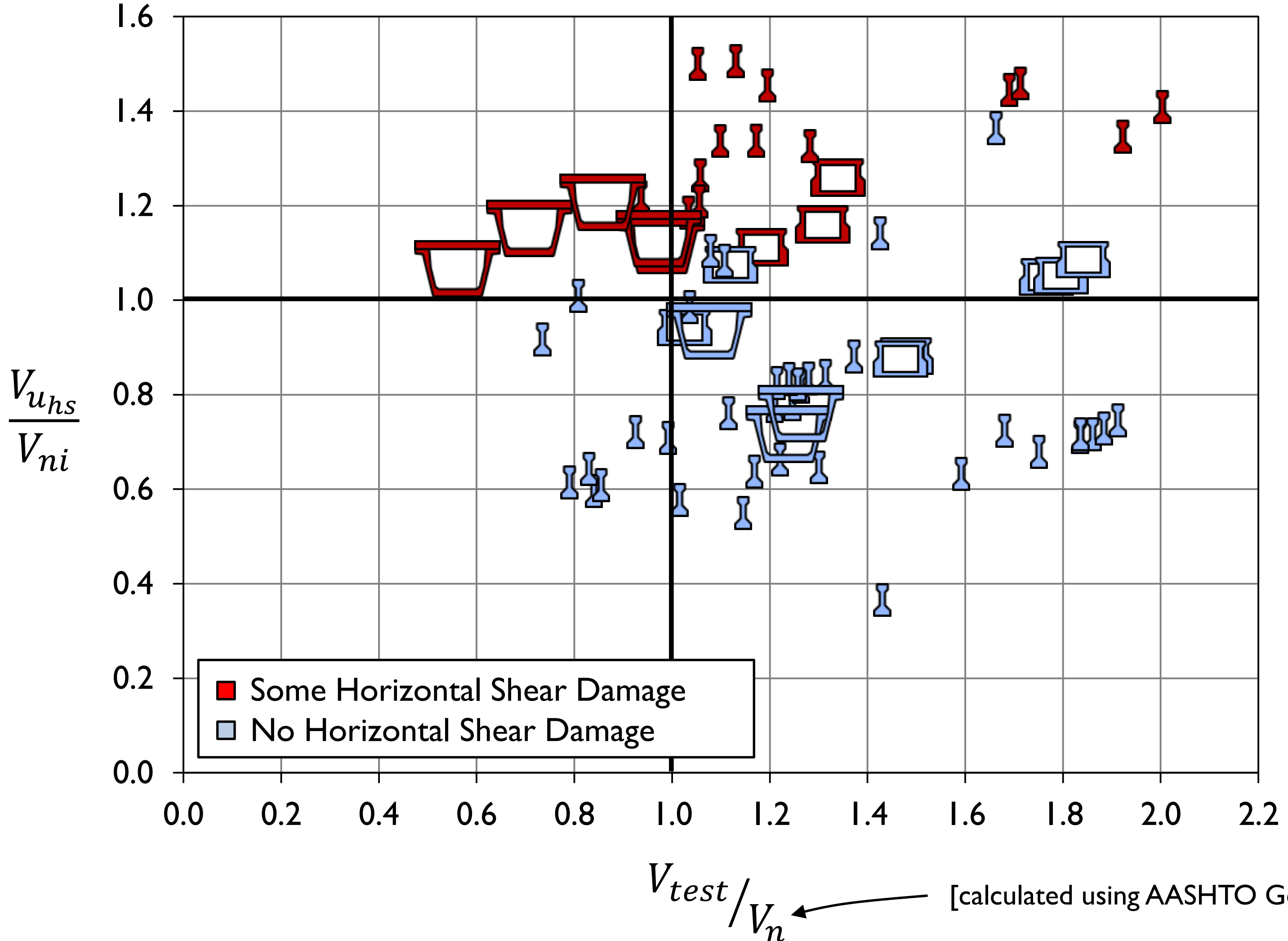
		Centered	Offset
Series 1	Measured Value	67.4 kip	54.7 kip
	Ratio to Calculated	0.91	0.73
Series 2	Measured Value	73.2 kip	60.1 kip
	Ratio to Calculated	0.98	0.81

Modified Push-Off Results

		Centered	Offset	Ratio: $\frac{\text{Offset}}{\text{Centered}}$
Series 1	Measured Value	67.4 kip	54.7 kip	0.81
	Ratio to Calculated	0.91	0.73	
Series 2	Measured Value	73.2 kip	60.1 kip	0.82
	Ratio to Calculated	0.98	0.81	

for U-Beams with offset reinforcement (i.e., no supplementary bars), reduce capacity with k_d equal to 0.8

Horizontal Shear Evaluation



[calculated using AASHTO General Procedure]