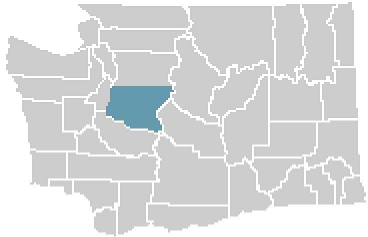
King County Roads Division
Seattle Washington

Proof Load Testing

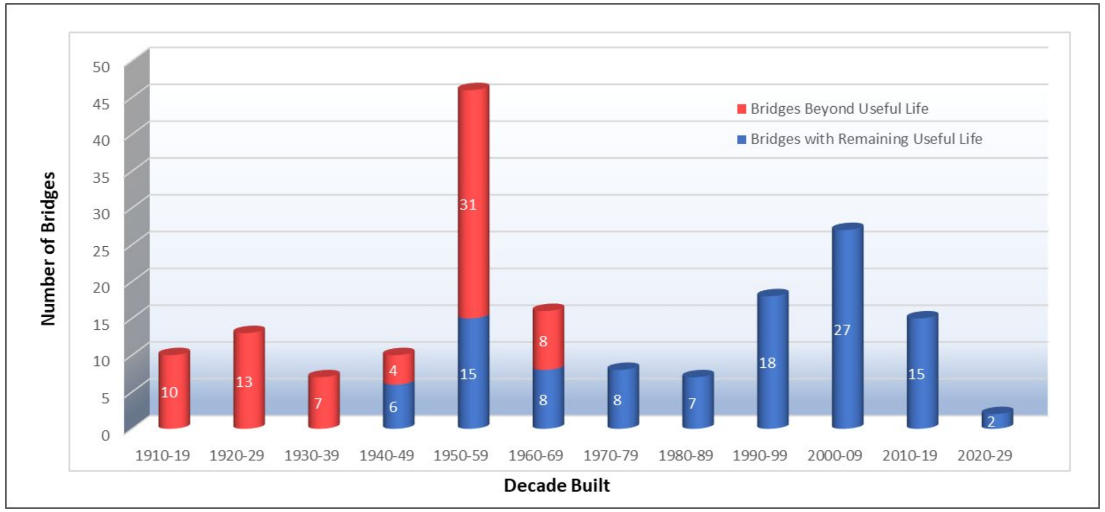
Short Span Precast Channel Beam Bridges

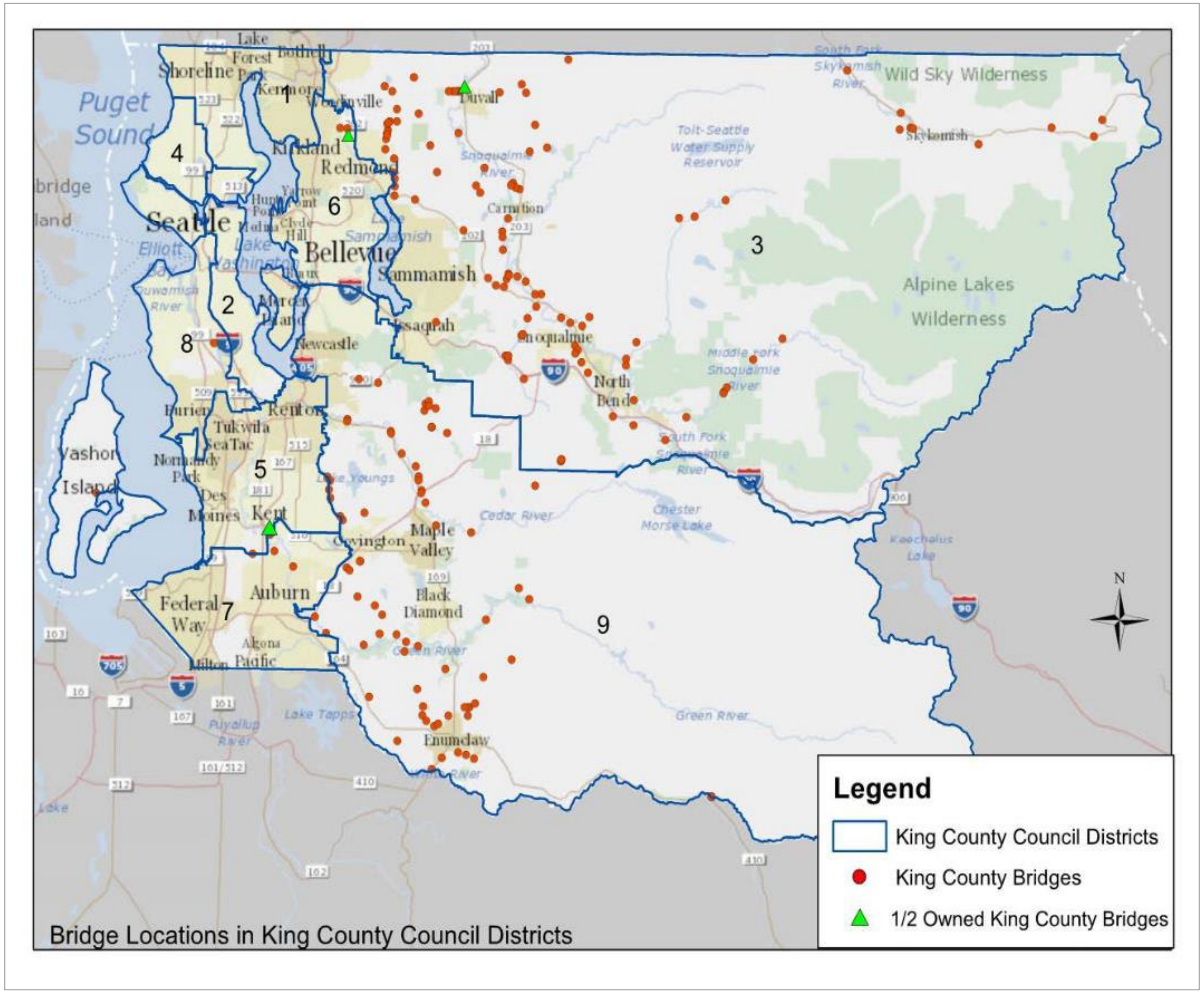
- Jason Lee, SE
- Senior Bridge Engineer
  - MSCE, University of Washington
    - Research assistant on CFST bridge piers
  - 10 years of bridge design as a consultant
  - 2 years at King County
  - Kiewit

King County



- 185 Bridges
  - 136 NBI Bridge
  - 45 short span bridges
  - 4 Pedestrian Bridges
  - Average bridge age = 52 years





King County

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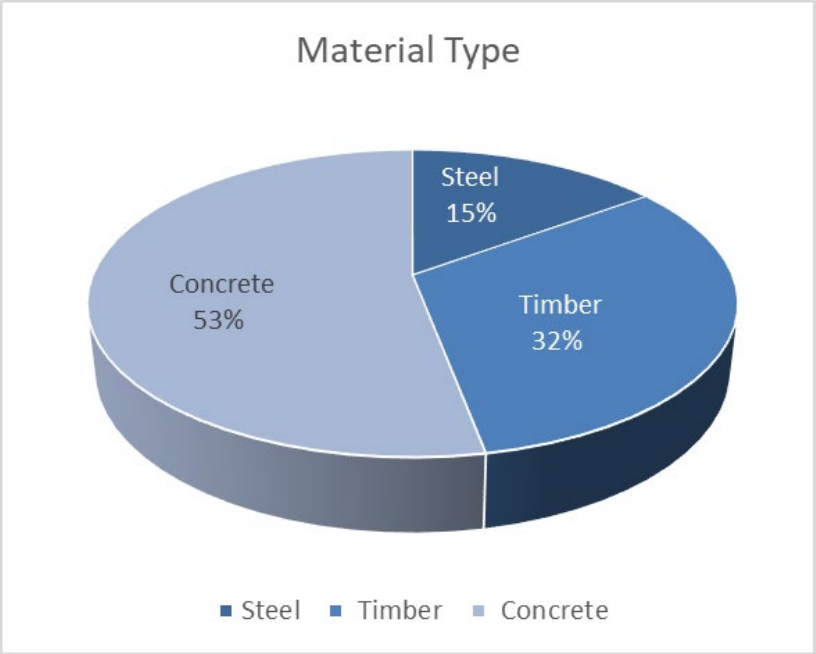
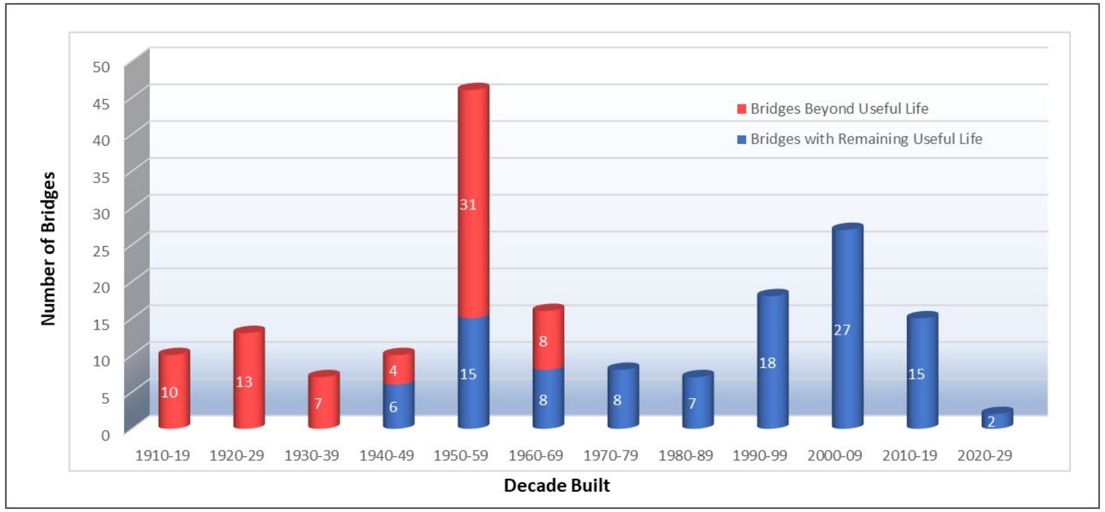
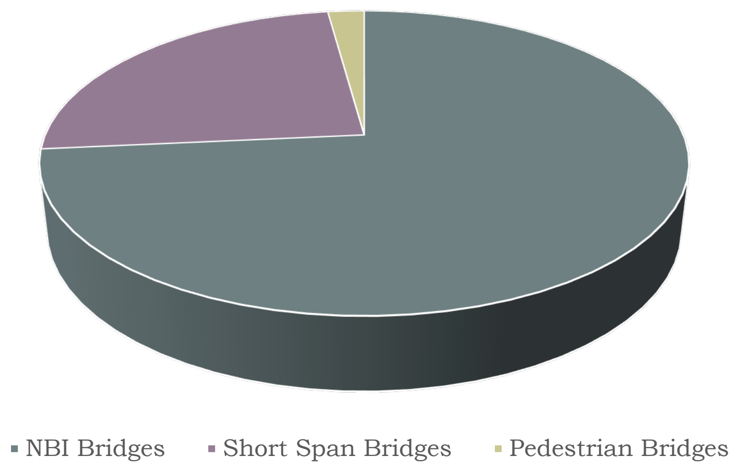
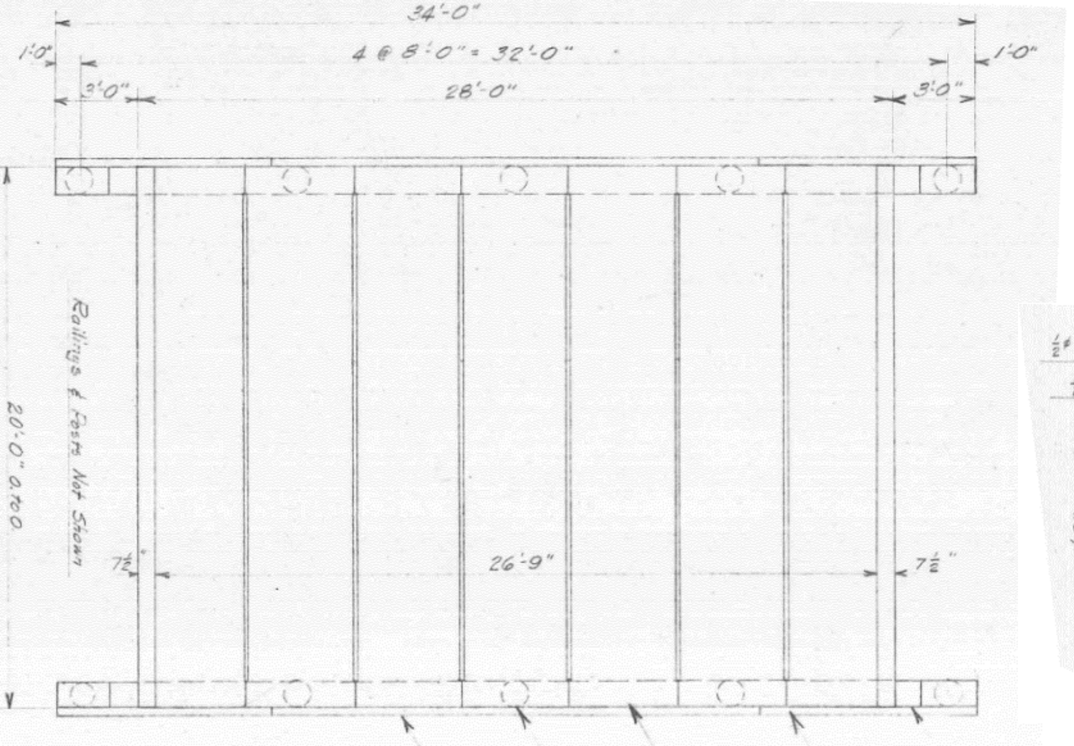




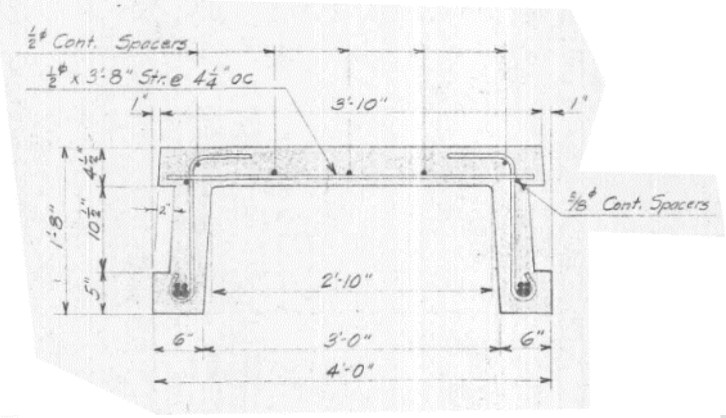
King County Bridge Distribution



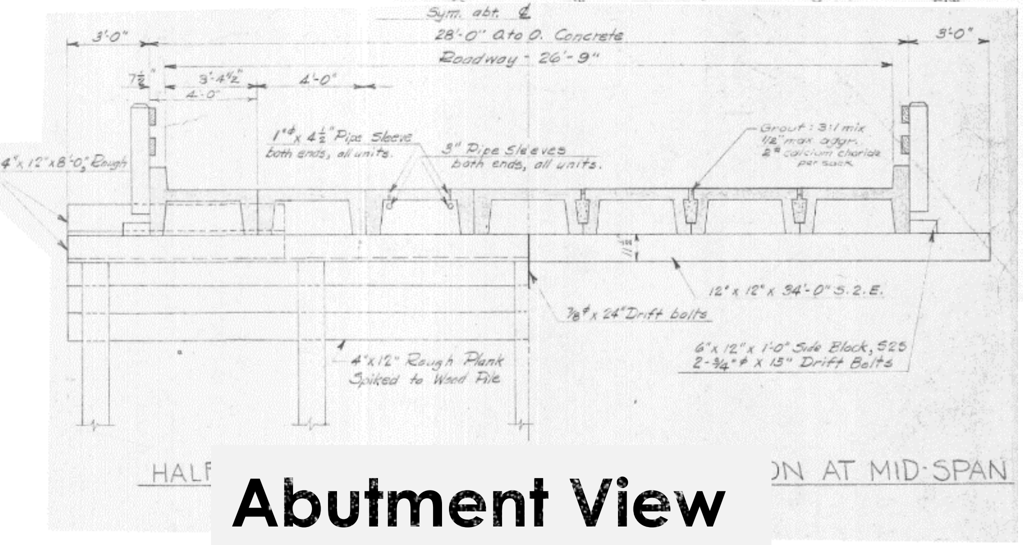
Short Span Channel Bridges



Plan



Girder Section



Abutment View

Br No.	Bridge Name	Age	ADT	Percent Trucks	Span
240A	Cottage Lake Creek Bridge	72	14,759	4%	20'
3097	Dorre Don Way Bridge	64	95	1%	20'
3099	Maxwell Road Bridge	72	520	0%	20'
228F	312th AVE SE Bridge	73	798	2%	20'
249C	C.W.Neal Bridge	72	99	2%	20'
578A	Evans Creek	73	170	5%	20'
916A	Pleasant Hill Rd	72	798	2%	20'
333A	Bear Creek Bridge	73	8,521	7%	20'
480A	Bear Creek Bridge	72	2,200	4%	20'
249B	C W Neal Road Bridge	72	99	3%	15.75'
909B	Clough Creek Bridge	72	1,328	3%	15.75'
3030	SE 380 St Bridge	73	760	2%	15.75'
3060	208th Ave SE Bridge	72	150	1%	15.75'
593C	May Creek Bridge	72	3,717	5%	15.75'
1086B	Coal Creek Bridge	73	459	1%	15.75'

Short Span Channel Bridges

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King County

BRIDGE RATING SUMMARY

SHYI-SHYONG JIANG
STATE OF WASHINGTON
28766
REGISTERED PROFESSIONAL ENGINEER
1-12-16
BRIDGE ENGINEER

Bridge Name: Clough Creek Bridge
Bridge Number: 909B
Span Types: Reinforced Concrete Multiple Web Grider
Bridge Length: 15.75 **feet**
Design Load: H15 **Year Built:** 1951
ADT/ADTT: 1228/37
Rating by: TTZ TTZ
Checked by: ZZ ZZ
Date: 11/9/2015

Inspect. Report Date	6/16/2015	Substructure Condition	6
Rating Method	LRFR	Deck Condition	5
Overlay Thickness	5.5	Superstructure Condition	5

Truck	RF	Tons	γ	Impact	Controlling Point
AASHTO 1 (Type 3)	0.91	23	1.30	0.33	Girder Shear
AASHTO 2 (Type 3S2)	1.04	38	1.30	0.33	Girder Shear
AASHTO 3 (Type 3-3)	1.20	48	1.30	0.33	Girder Shear
NRL	0.79	32	1.30	0.33	Girder Shear
SU-4	0.79	21	1.30	0.33	Girder Shear
SU-5	0.79	24	1.30	0.33	Girder Shear
SU-6	0.79	27	1.30	0.33	Girder Shear
SU-7	0.79	31	1.30	0.33	Girder Shear
OL-1	0.72	35	1.20	0.33	Girder Shear
OL-2	0.61	64	1.20	0.33	Girder Shear
UBIT-30	1.50	23	1.20	0.33	Girder Mid-Span Flexure
UBIT-60	0.97	32	1.20	0.33	Girder Shear

NBI Rating

Truck	RF	Tons	γ	Impact	Controlling Point
Inventory (HL-93)	0.28	10	1.75	0.33	Girder Shear
Operating (HL-93)	0.41	15	1.35	0.33	Girder Shear

Note: Inventory and Operating tonnages are based on the rating factors multiply 36 tons (HS-20 Truck)

Load Rating Toolbox

Analytical Load Ratings
(MBE § 6, Part A/Part B)

- Analysis using design values and conventional assumptions.
- Can be enhanced with material testing

Diagnostic Load Testing
(MBE § 8.8.2)

- Nondestructive testing to improve the engineers understanding of the bridge behavior.
- Typically uses gauges and other measuring devices to measure the behavior of the bridge.
- Analytical model used for final load rating built off the data created during testing.

Proof Load Testing
(MBE § 8.8.3)

- Field load testing and observation used to determine if the bridge can carry specific loads without damage.

Material Testing

- Concrete Strength Testing
  - 2.75” Ø core through girder flange
  - 8 cores from 16ft channel beams
  - 8 cores from 20ft channel beams
- Reinforcing Steel Material Testing
  - 6” coupons from flange and web
  - 3 samples from16ft channel beams
  - 3 samples from 20ft channel beams

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Results

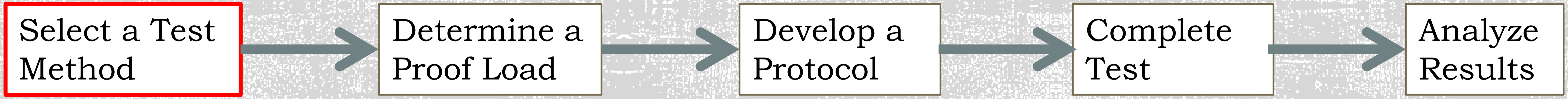
- Resulting Concrete Strength =
  - F’c = 4.5 ksi
- Resulting Steel Strength =
  - Fy = 55 ksi
  - Fu = 86 ksi

Why Proof Load Testing??

- The results of analytical methods and material testing did not show sufficient capacity.
- Diagnostic load testing was cost prohibitive.
- Routine inspections indicated the channel girders were in fair to satisfactory condition.
- Access to beams from decommissioned bridges we could test in our maintenance yard.

Proof Load Testing

Selecting a Test Method



Selecting a Testing Method

Truck/Axle Loads

Laboratory Setting

Self Perform

Selecting a Testing Method

Why Self Perform?

Pros

- Lowest cost
- Most control over schedule and process

Cons

- Fewer data collection opportunities
- Limited monitoring
- Limited load capacity

Proof Load Testing

Determine the Proof Load

Select a Test Method → **Determine a Proof Load** → Develop a Protocol → Complete Test → Analyze Results

Proof Load Tests (MBE §8.8.3)

- Approach
  - Determine critical load demands on structure
  - Select a Target Proof Load
  - Apply Target Proof Load
    - Apply load in stages
    - Closely monitor structure at each stage of loading.
    - Incremental loading should continue until desired load is reached or bridge exhibits visible signs of distress.

- Selecting a Target Proof Load

$$X_{pA} = X_p\left(1+\frac{\Sigma\%}{100}\right) \quad (8.8.3.3.2\text{-}1)$$

The target proof load L_T is then:

$$L_T = X_{pA}L_R(1+IM) \quad (8.8.3.3.2\text{-}2)$$

where:

L_R = comparable unfactored live load due to the rating vehicle for the lanes loaded

IM = dynamic load allowance

X_{pA} = target adjusted live-load factor

Table 8.8.3.3.1-1—Adjustments to X_p

Consideration	Adjustment
One-Lane Load Controls	+15%
Nonredundant Structure	+10%
Fracture-Critical Details Present	+10%
Bridges in Poor Condition	+10%
In-Depth Inspection Performed	−5%
Rateable, Existing $RF \geq 1.0$	−5%
$ADTT \leq 1{,}000$	−10%
$ADTT \leq 100$	−15%

Proof Load Tests (MBE §8.8.3)

- Example Target Proof Load
- Shear near support from NRL
  - L_R = 20 Kip
  - X_p =1.4
  - $X_{pA} = X_p(1 + \frac{\sum \%}{100})$= 1.4 $(1 + \frac{15\%}{100})$=1.61
  - $L_T = X_{pA} L_R (1+IM)$ =1.61*20*(1.33) =43 Kip

  - Capacity and Rating
  - $OP = \frac{k_o L_p}{X_{pA}}$

Table 8.8.3.3.3-1—Values for k_O

Terminated	k_O
Reached Target Load	1.00
Reached Distress Level	0.88

- Selecting a Target Proof Load

- Example Target Proof Load
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Rateable, Existing $RF \geq 1.0$	−5%
$ADTT \leq 1{,}000$	−10%
$ADTT \leq 100$	−15%

Proof Load Testing

Develop a Protocol

Select a Test Method → Determine a Proof Load → Develop a Protocol → Complete Test → Analyze Results

Developing a Protocol

Flexure Proof Load

Test Load	TL Magnitude	Total Moment	Notes
Proof Load (k-in	2495	2890	Target Shear load
Stage 1	623.75	1019	0.25*proof load
Stage 2	1247.5	1643	0.5*proof load
Stage 3	1871.25	2266	0.75*proof load
Stage 4	2183.125	2578	0.875*proof load
Stage 5	2495	2890	target proof load
Stage 6	2744.5	3140	1.1*proof load
Stage 7	2994	3389	1.2*proof load
Stage 8	3243.5	3639	1.3*proof load
Stage 9	3628	4023	1.4*proof load

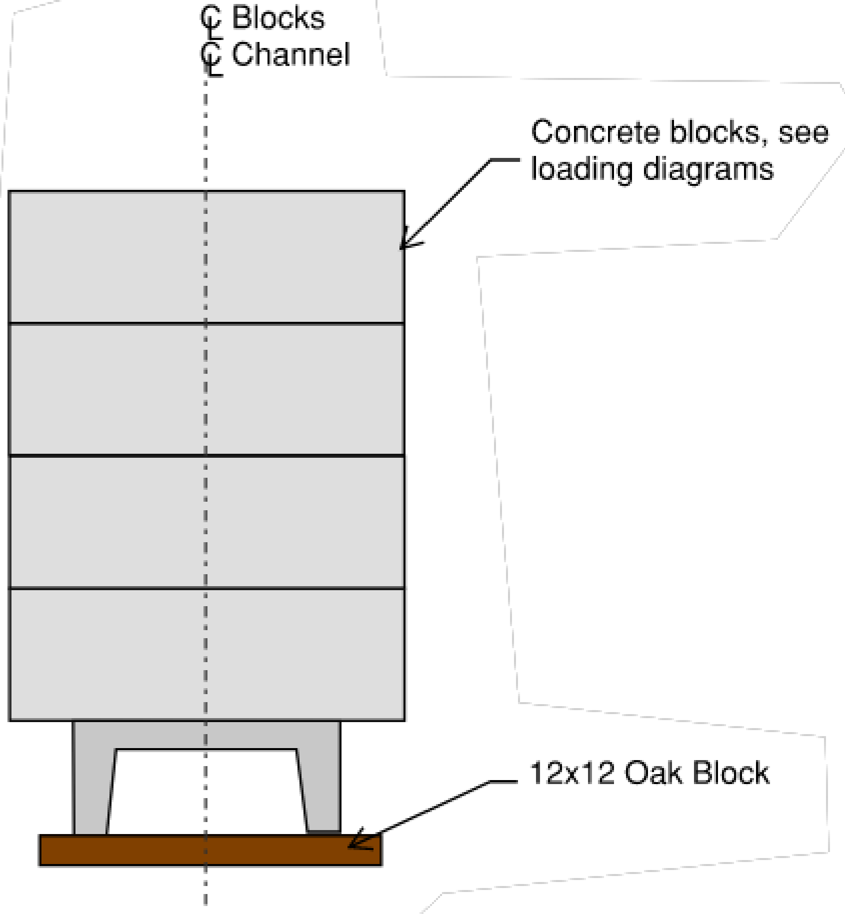
*unfactored dead load demands = 395 k-in

Shear Proof Load

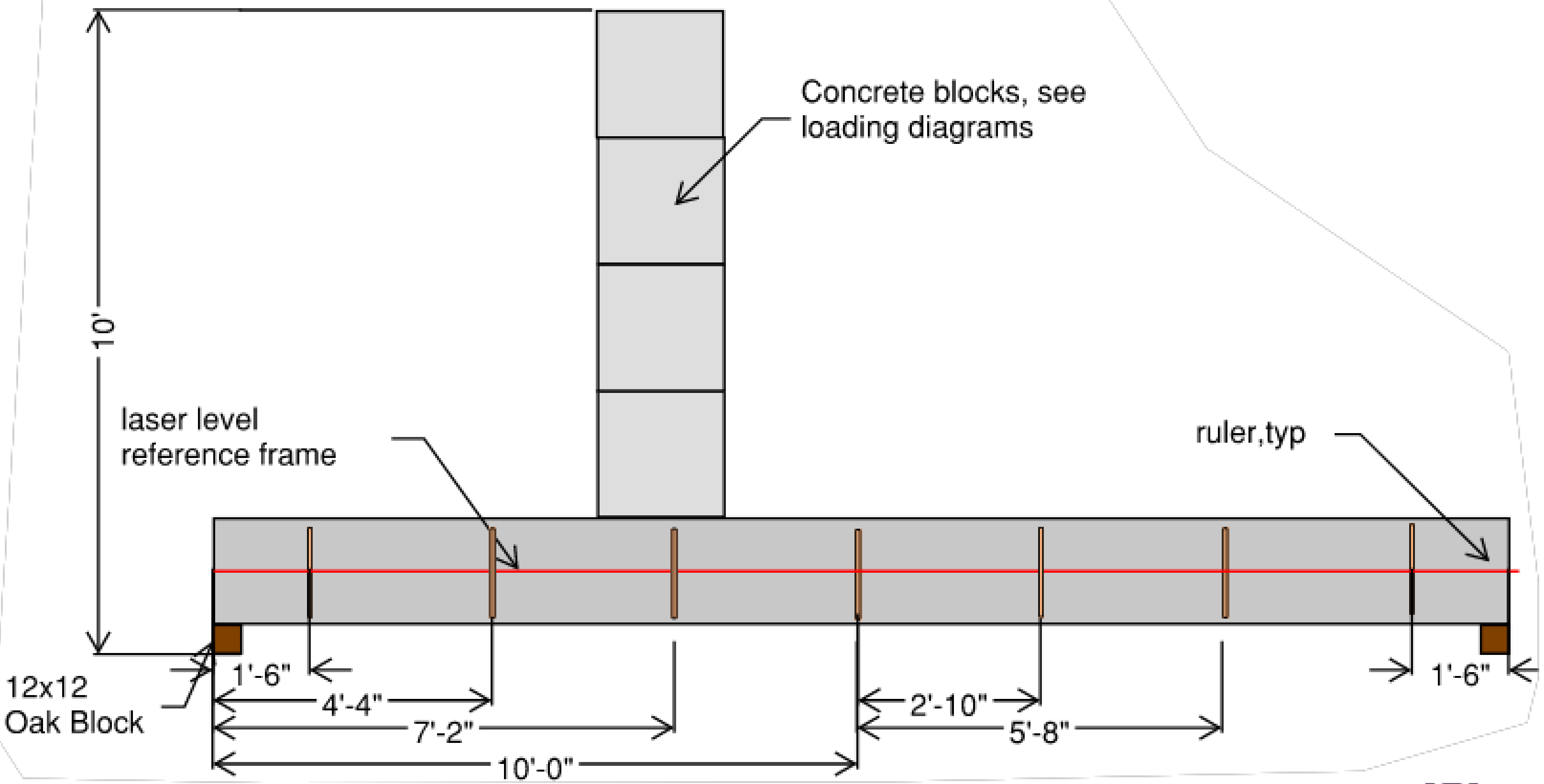
Test Load	TL Magnitude	Total Shear	Load
Proof Load (kip)	42	48	Target Shear load
Stage 1	10.5	16	0.25*proof load
Stage 2	21	27	0.5*proof load
Stage 3	31.5	37	0.75*proof load
Stage 4	36.75	42	0.875*proof load
Stage 5	42	48	target proof load
Stage 6	46.2	52	1.1*proof load
Stage 7	50.4	56	1.2*proof load
Stage 8	54.6	60	1.3*proof load
Stage 9	56.8	62	1.4*proof load

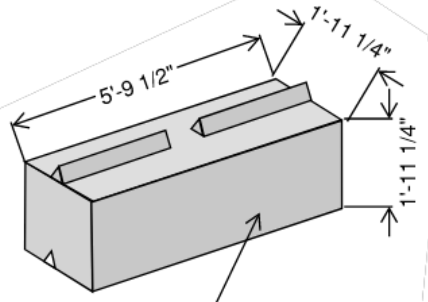
*unfactored dead load demands = 5.5 kips

Developing a Protocol



Section View

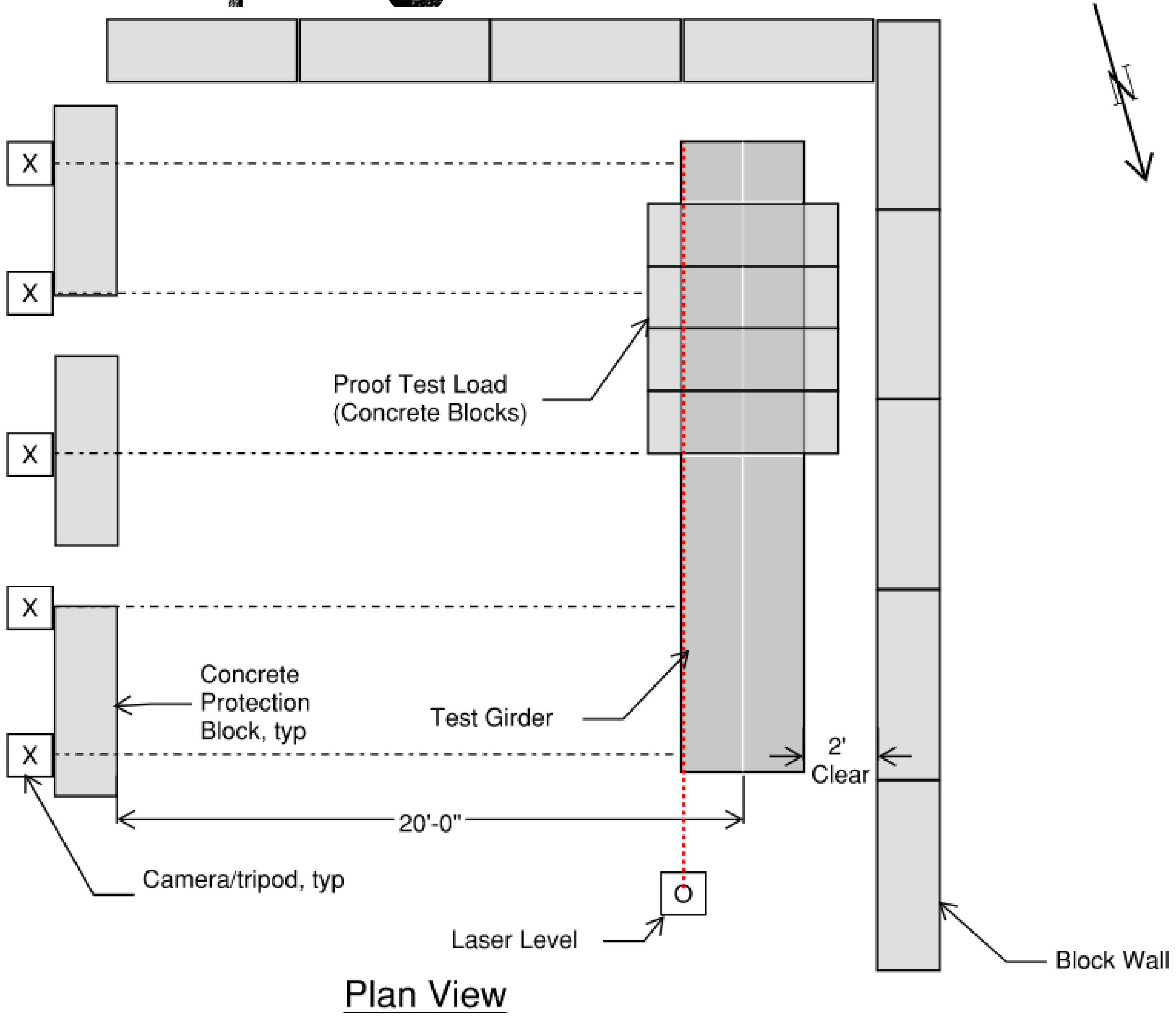




Nominal concrete block size. Blocks weigh 3-3.8kips depending on concrete density. Blocks should be weighed to confirm weight.

TYPICAL BLOCK

Developing a Protocol



- Cameras set for high resolution photos
- Rulers and reference line set for deflection measurements
- Beam set in loading area with access behind wall for adding loading blocks
- Staffing
  - Test Manager
  - Recorder 1
  - Recorder 1
  - Operator 1
  - Safety Officer

Proof Load Testing

Conduct Test

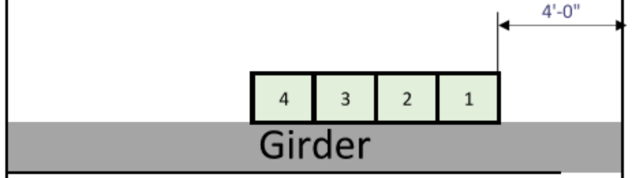
Select a Test Method → Determine a Proof Load → Develop a Protocol → **Conduct Test** → Analyze Results

Test and Stage Detail

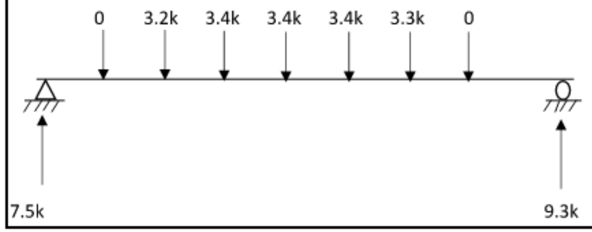
Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 1 (25% of Flexure Proof Load)
blocks: 4 blocks
Applied Weight: 17 k
Total Weight 24 k
Max Moment: 711.3 k-in
Approx shear @ dv: 9.3k

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

BLOCK CONFIGURATION

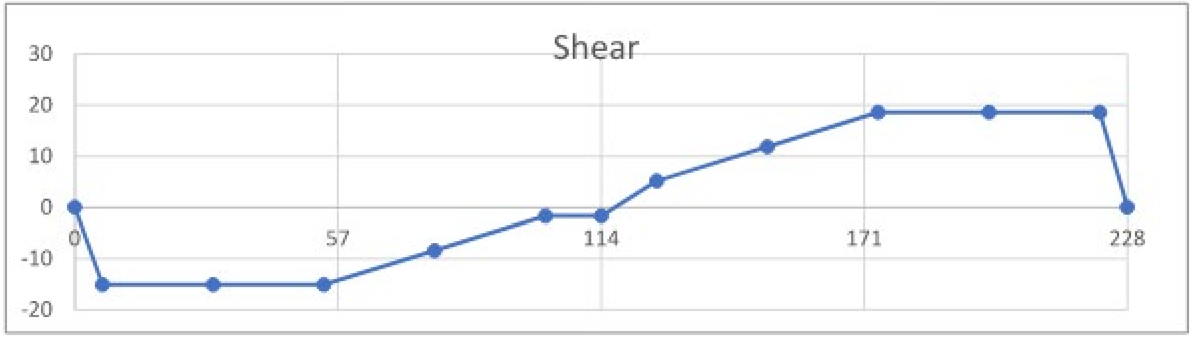


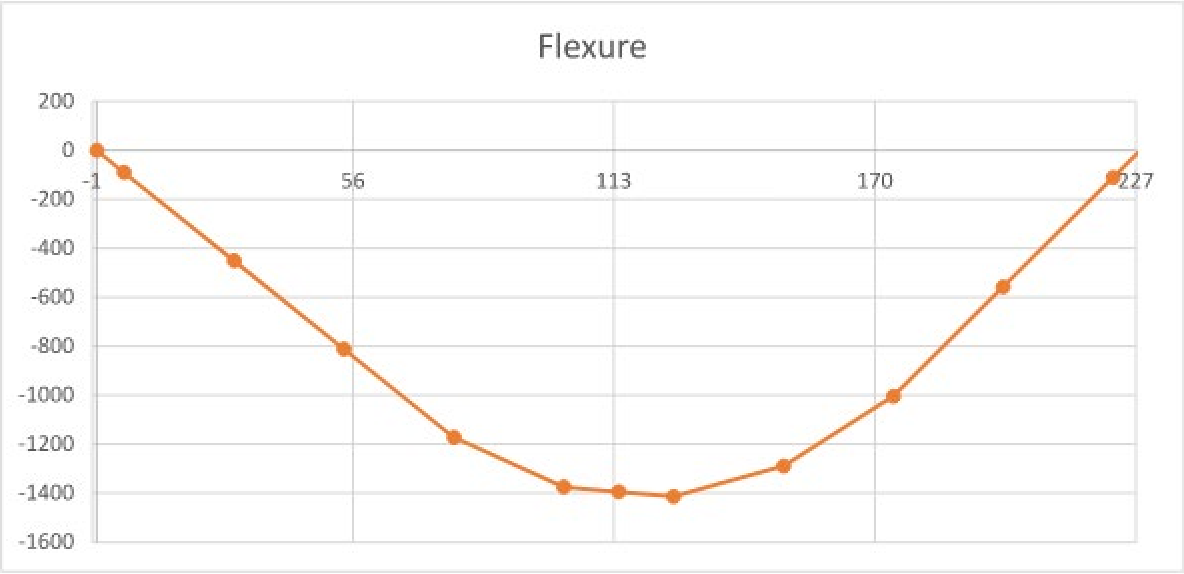
IDEALIZED LOAD DIAGRAM



NOTES:

$M_{mid\ spa}$





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blocks: 4 blocks

Applied Weight: 17 k

Total Weight 24 k

Max Moment: 711.3 k-in

Approx shear @ dv: 9.3k

Test and Stage Detail

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V_n = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

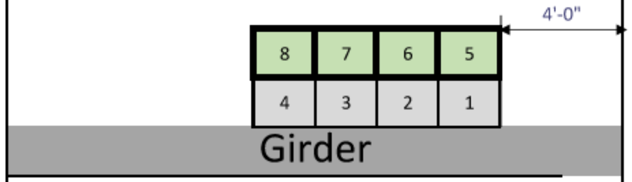
Specimen #:	20-B
Span Length:	20'-0"
Protocol:	Flexure Proof Load
Stage:	1 (25% of Flexure Proof Load)
blocks:	4 blocks
Applied Weight:	17 k
Total Weight	24 k
Max Moment:	711.3 k-in
Approx shear @ dv:	9.3k

Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 2 (50% of Flexure Proof Load)
blocks: 8 blocks
Applied Weight: 34 k
Total Weight 40 k
Max Moment: 1414.3 k-in
Approx shear @ dv: 18.6k

BLOCK CONFIGURATION



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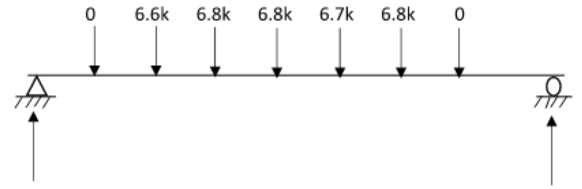

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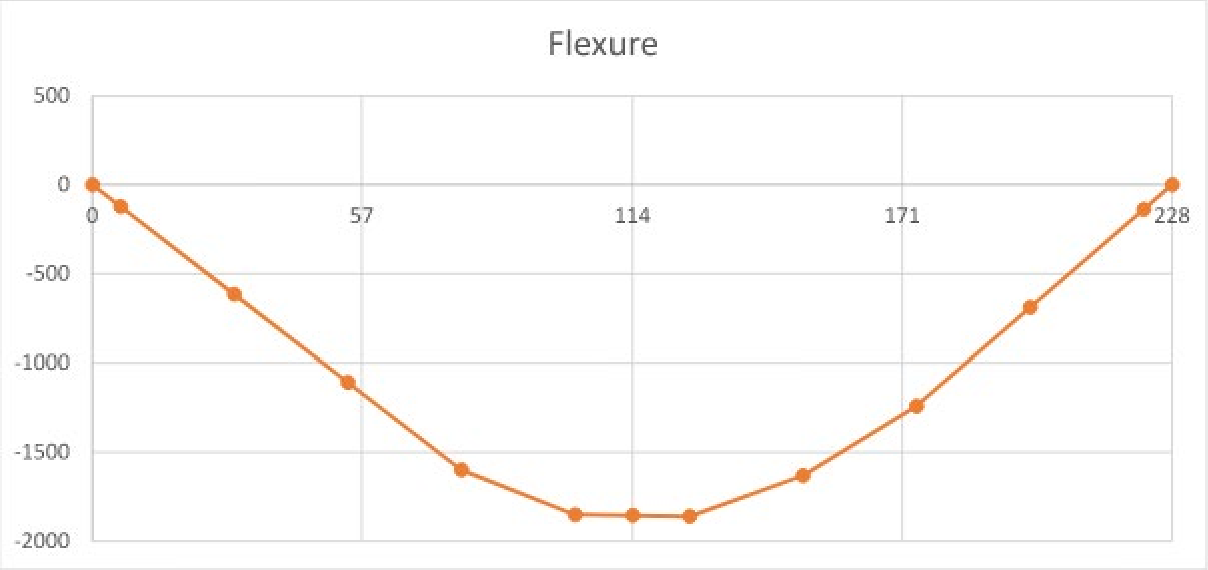

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Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 2 (50% of Flexure Proof Load)

blocks: 8 blocks

Applied Weight: 34 k

Total Weight 40 k

Max Moment: 1414.3 k-in

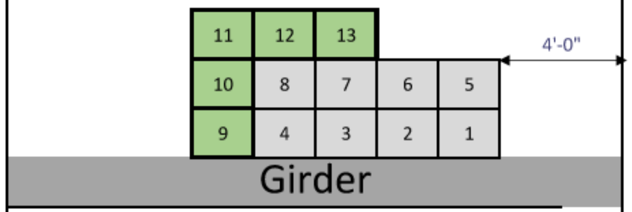
Approx shear @ dv: 18.6k

Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 3 (75% of Flexure Proof Load)
blocks: 13 blocks
Applied Weight: 44 k
Total Weight 50 k
Max Moment: 1860.7 k-in
Approx shear @ dv: 23.k

BLOCK CONFIGURATION



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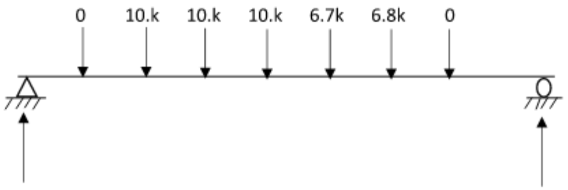

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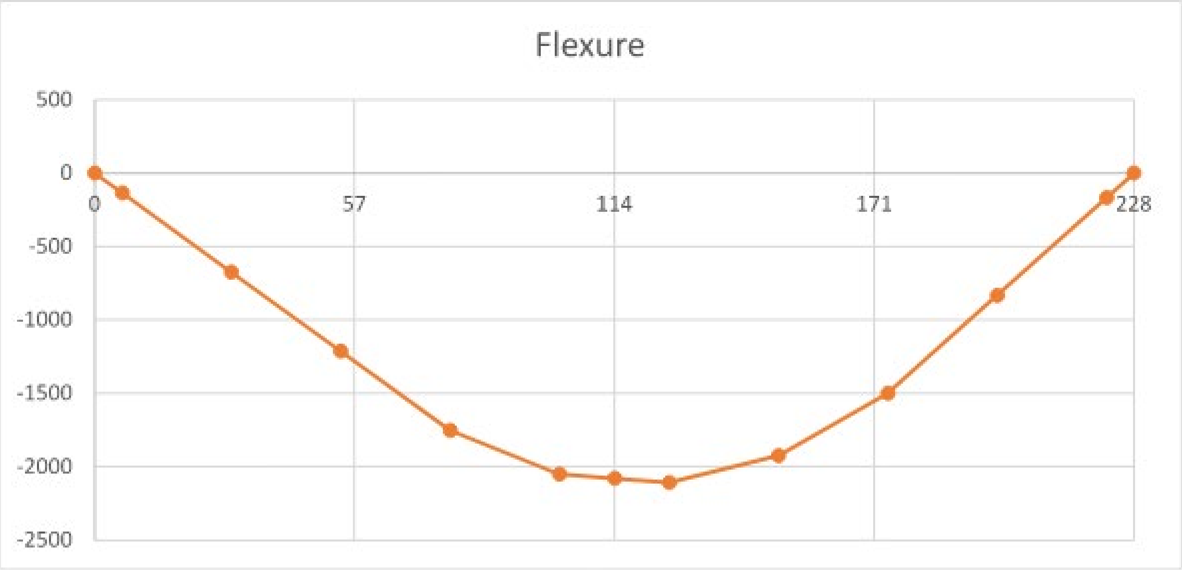

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Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 3 (75% of Flexure Proof Load)

blocks: 13 blocks

Applied Weight: 44 k

Total Weight 50 k

Max Moment: 1860.7 k-in

Approx shear @ dv: 23.k

Test and Stage Detail

M_n = 2868 k-in

V_n = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 4 (87.5% of Flexure Proof Load)

blocks: 15 blocks

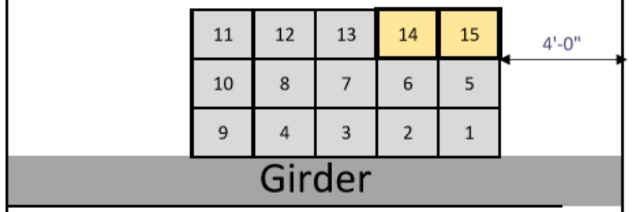
Applied Weight: 50 k

Total Weight 57 k

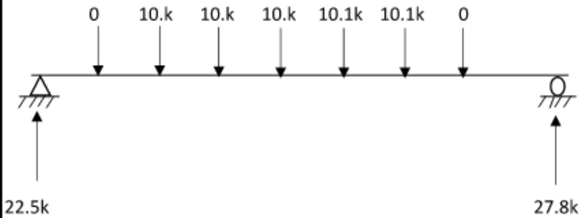
Max Moment: 2107.8 k-in

Approx shear @ dv: 27.8k

BLOCK CONFIGURATION

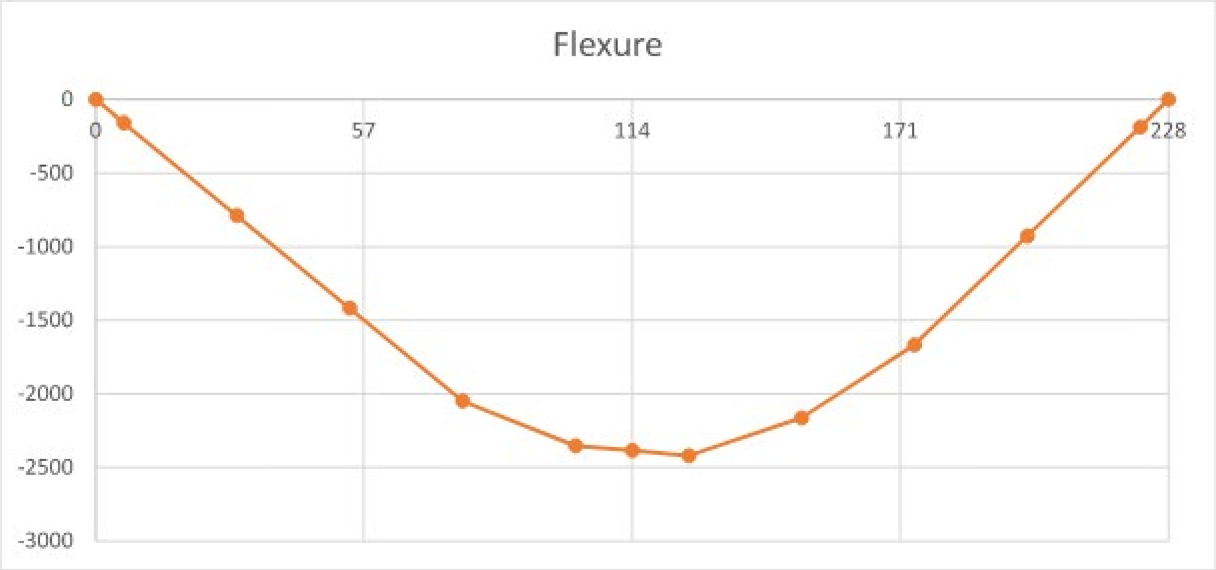


IDEALIZED LOAD DIAGRAM



NOTES:

$M_{mid\ spa}$



Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

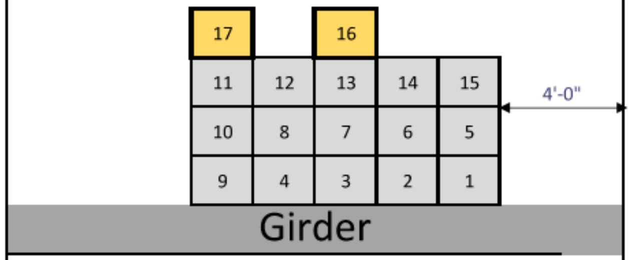
Specimen #:	20-B
Span Length:	20'-0"
Protocol:	Flexure Proof Load
Stage:	4 (87.5% of Flexure Proof Load)
blocks:	15 blocks
Applied Weight:	50 k
Total Weight	57 k
Max Moment:	2107.8 k-in
Approx shear @ dv:	27.8k

Test and Stage Detail

Mn = 2868 k-in
Vn = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

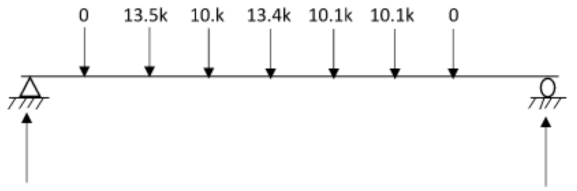
Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 5 (100% of Flexure Proof Load)
blocks: 17 blocks
Applied Weight: 57 k
Total Weight 64 k
Max Moment: 2419.5 k-in
Approx shear @ dv: 30.9k

BLOCK CONFIGURATION

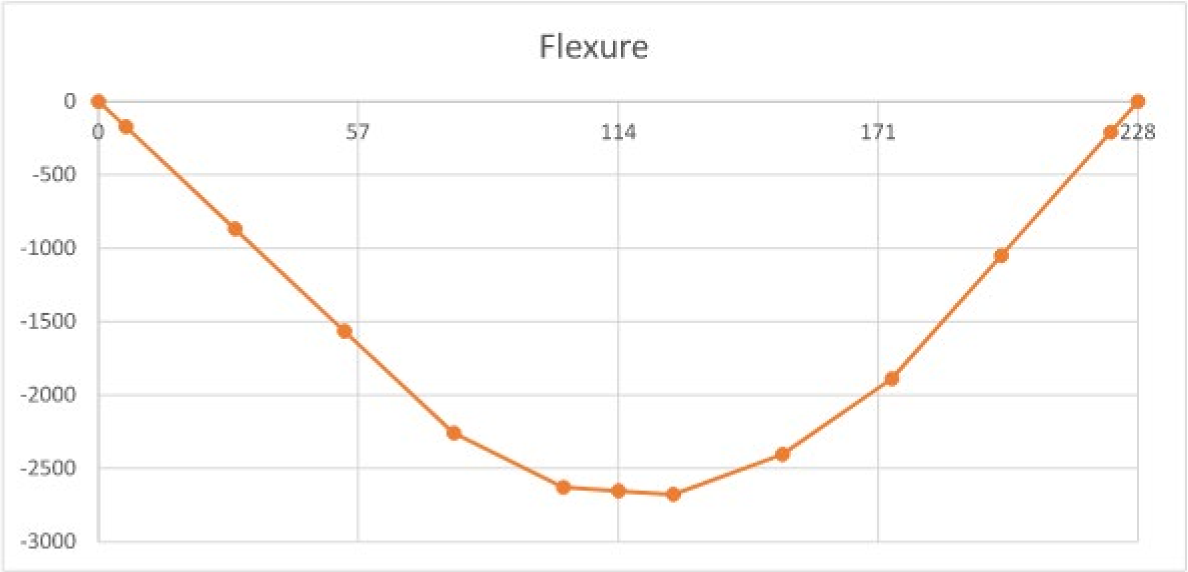


NOTES:

IDEALIZED LOAD DIAGRAM



$M_{mid\ spa}$



Test and Stage Detail

Mn = 2868 k-in

Vn = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 5 (100% of Flexure Proof Load)

blocks: 17 blocks

Applied Weight: 57 k

Total Weight 64 k

Max Moment: 2419.5 k-in

Approx shear @ dv: 30.9k

Test and Stage Detail

Mn = 2868 k-in

Vn = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 6 (110% of Flexure Proof Load)

blocks: 19 blocks

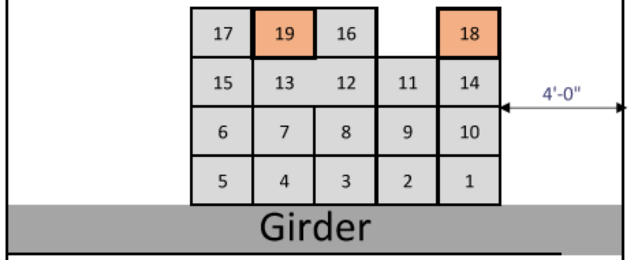
Applied Weight: 64 k

Total Weight 71 k

Max Moment: 2677.9 k-in

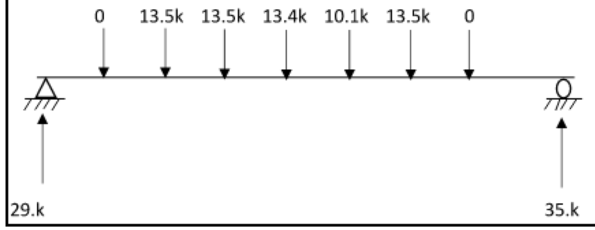
Approx shear @ dv: 35.k

BLOCK CONFIGURATION

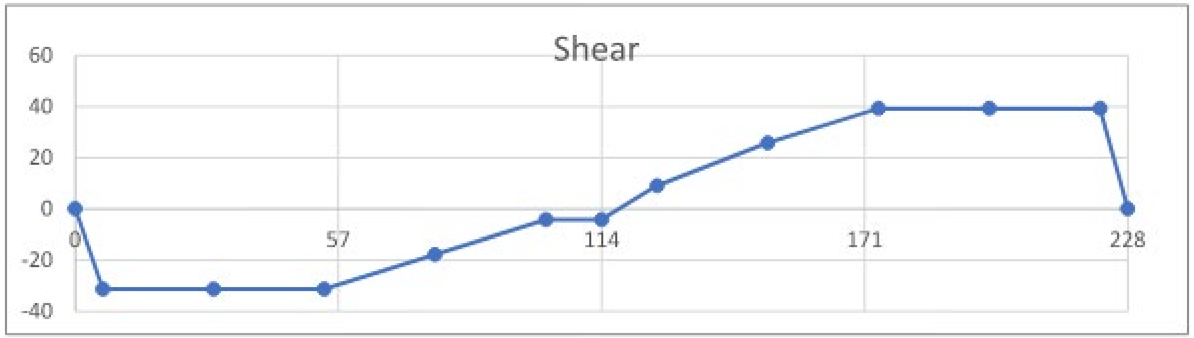


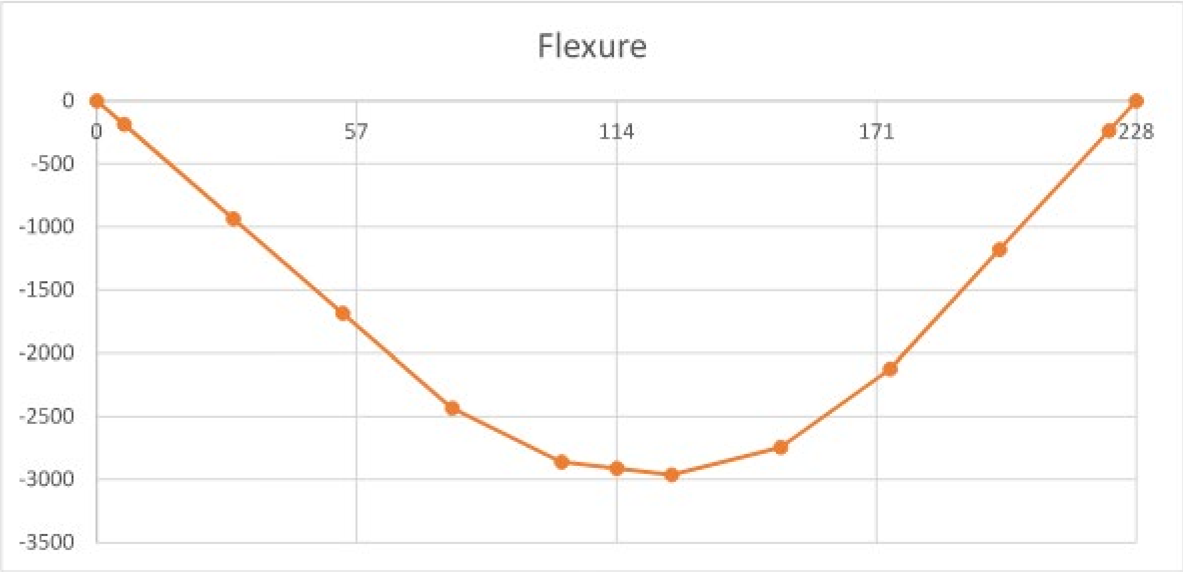
NOTES:

IDEALIZED LOAD DIAGRAM



$M_{mid spa}$





Test and Stage Detail

Mn = 2868 k-in

Vn = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 6 (110% of Flexure Proof Load)

blocks: 19 blocks

Applied Weight: 64 k

Total Weight 71 k

Max Moment: 2677.9 k-in

Approx shear @ dv: 35.k

Test and Stage Detail

M_n = 2868 k-in

V_n = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 7 (120% of Flexure Proof Load)

blocks: 21 blocks

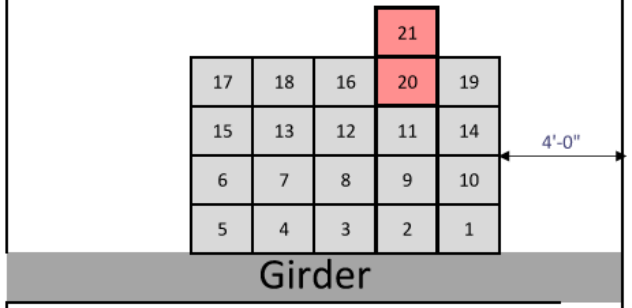
Applied Weight: 71 k

Total Weight 77 k

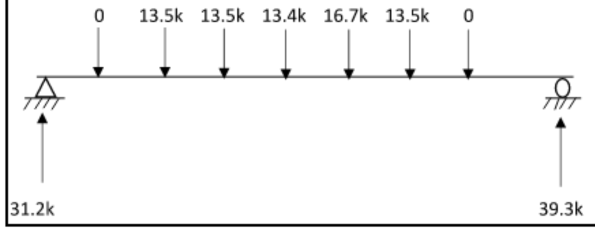
Max Moment: 2963.3 k-in

Approx shear @ dv: 39.3k

BLOCK CONFIGURATION

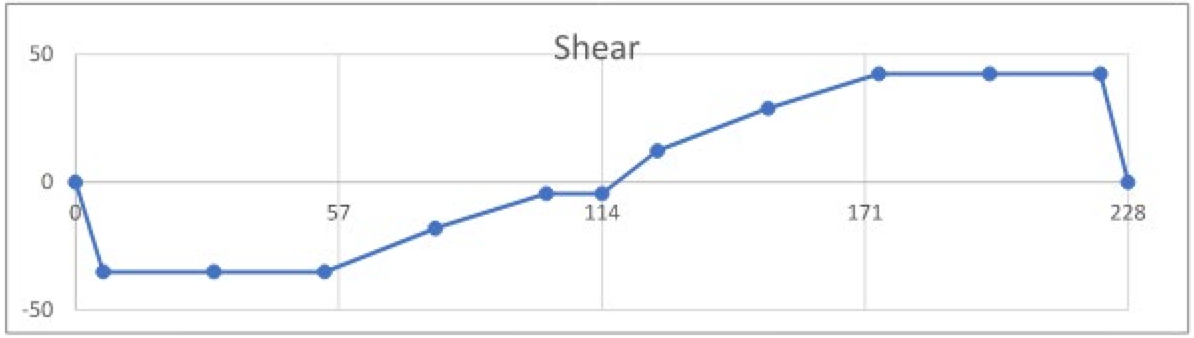


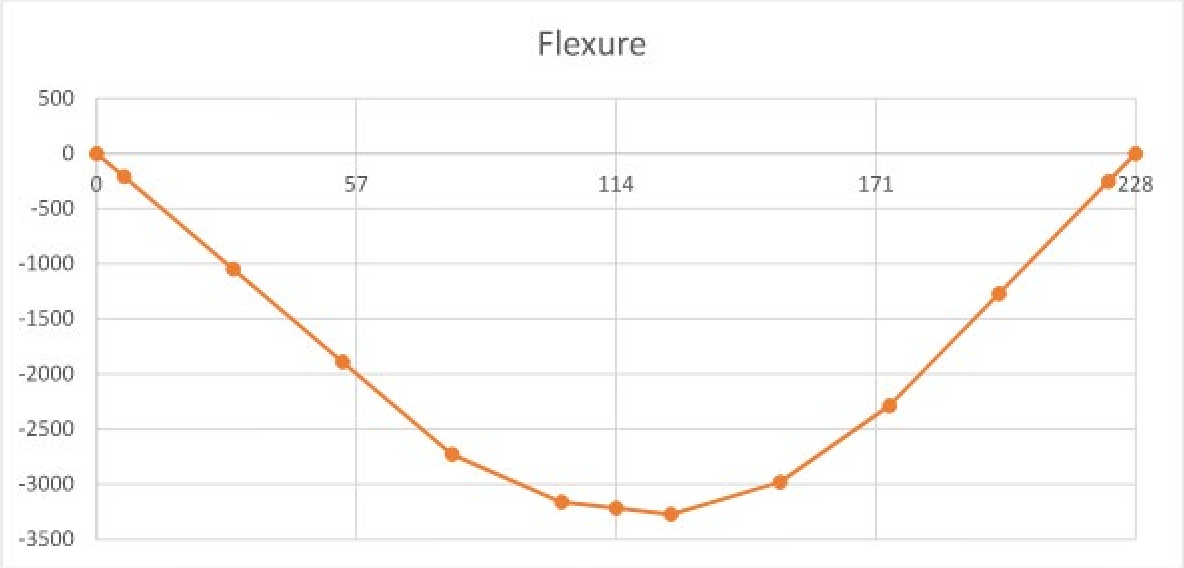
IDEALIZED LOAD DIAGRAM



NOTES:

$M_{mid\ spa}$





Test and Stage Detail

Mn = 2868 k-in
Vn = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

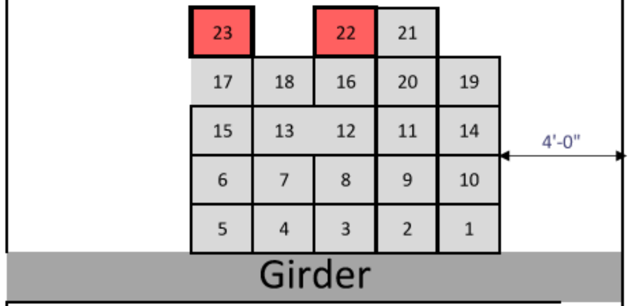
Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 7 (120% of Flexure Proof Load)
blocks: 21 blocks
Applied Weight: 71 k
Total Weight 77 k
Max Moment: 2963.3 k-in
Approx shear @ dv: 39.3k

Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

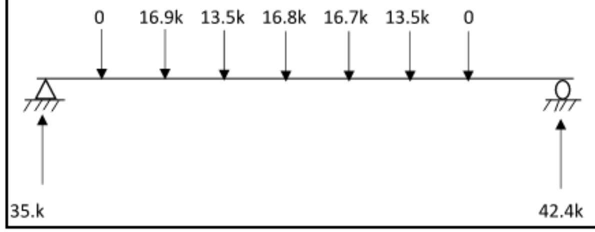
Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 8 (130% of Flexure Proof Load)
blocks: 23 blocks
Applied Weight: 77 k
Total Weight 84 k
Max Moment: 3273.9 k-in
Approx shear @ dv: 42.4k

BLOCK CONFIGURATION

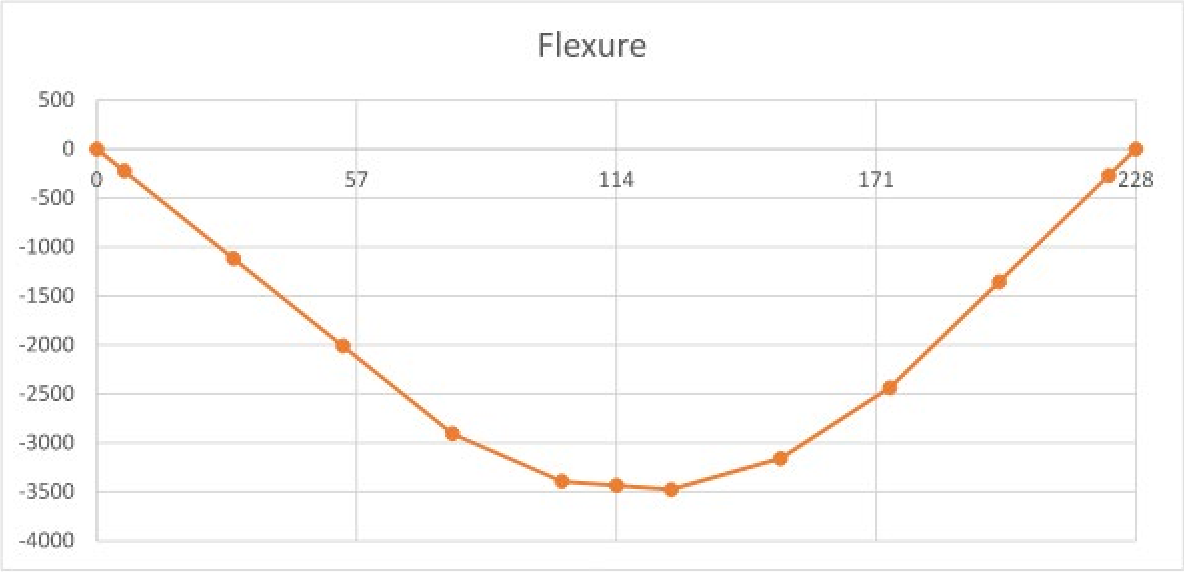


NOTES:

IDEALIZED LOAD DIAGRAM



$M_{mid\ spa}$



Test and Stage Detail

M_n = 2868 k-in

V_n = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

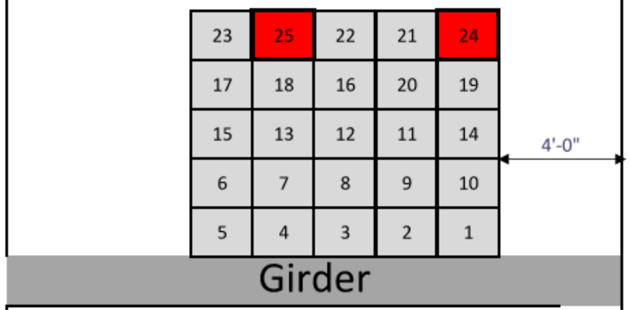
Specimen #:	20-B
Span Length:	20'-0"
Protocol:	Flexure Proof Load
Stage:	8 (130% of Flexure Proof Load)
blocks:	23 blocks
Applied Weight:	77 k
Total Weight	84 k
Max Moment:	3273.9 k-in
Approx shear @ dv:	42.4k

Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

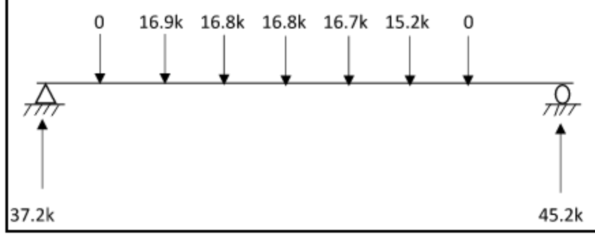
Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 9 (140% of Flexure Proof Load)
blocks: 25 blocks
Applied Weight: 82 k
Total Weight 89 k
Max Moment: 3477. k-in
Approx shear @ dv: 45.2k

BLOCK CONFIGURATION

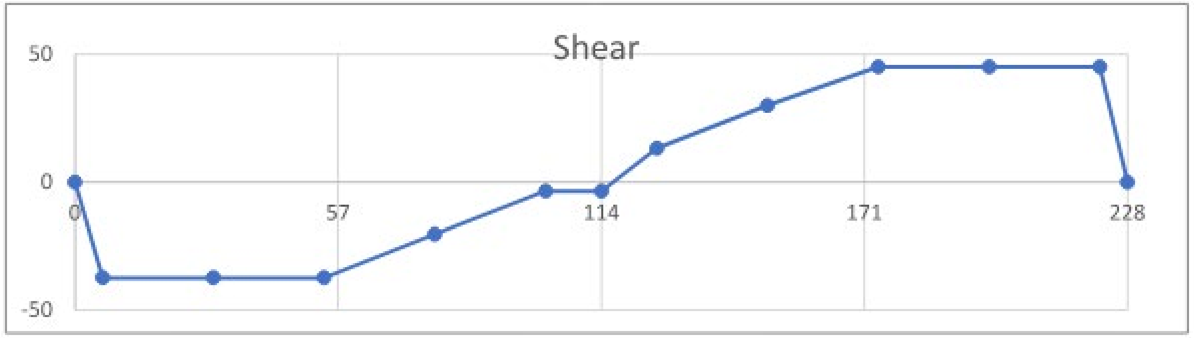


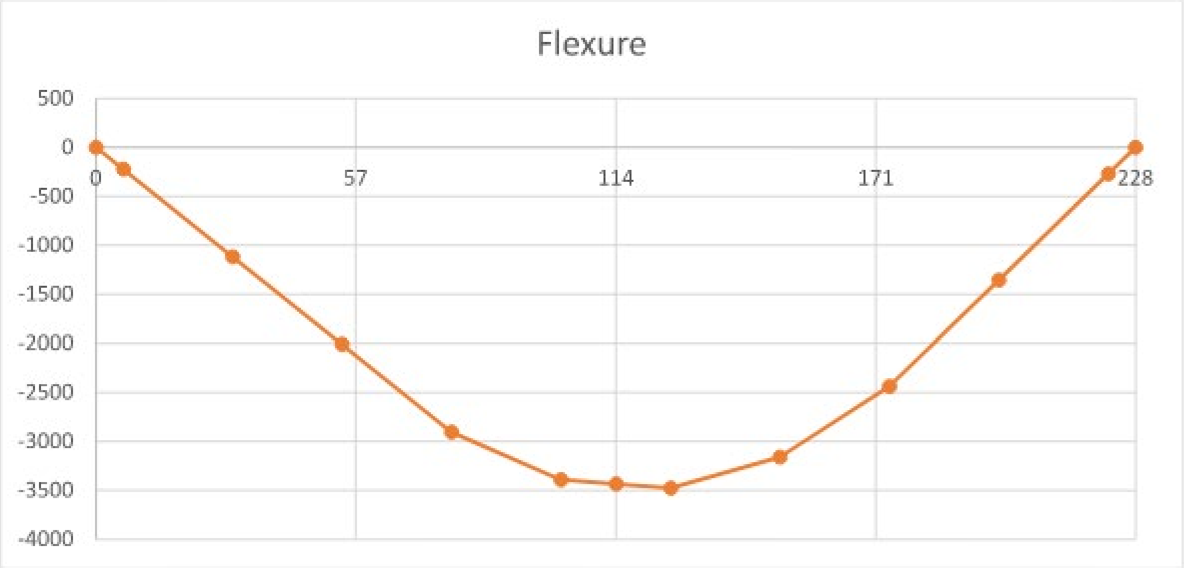
NOTES:

IDEALIZED LOAD DIAGRAM



$M_{mid\ spa}$





Test and Stage Detail

M_n = 2868 k-in
V_n = 53.6 kip
M_{proof} = 2495 k-in
V_{proof} = 42 kip

Specimen #: 20-B
Span Length: 20'-0"
Protocol: Flexure Proof Load
Stage: 9 (140% of Flexure Proof Load)
blocks: 25 blocks
Applied Weight: 82 k
Total Weight 89 k
Max Moment: 3477. k-in
Approx shear @ dv: 45.2k

Test and Stage Detail

M_n = 2868 k-in

V_n = 53.6 kip

M_{proof} = 2495 k-in

V_{proof} = 42 kip

Specimen #: 20-B

Span Length: 20'-0"

Protocol: Flexure Proof Load

Stage: 10 (140% of Flexure Proof Load)

blocks: 30 blocks

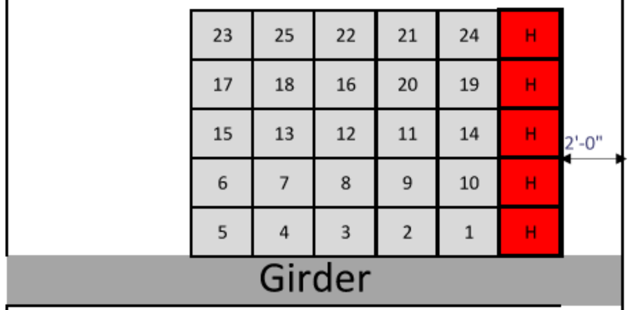
Applied Weight: 82 k

Total Weight 89 k

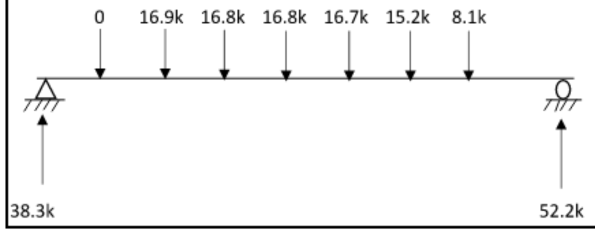
Max Moment: 3610.6 k-in

Approx shear @ dv: 52.2k

BLOCK CONFIGURATION

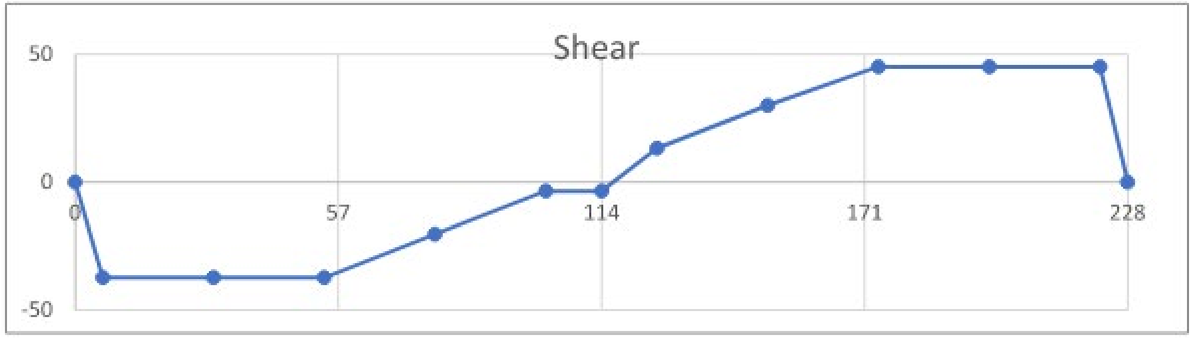


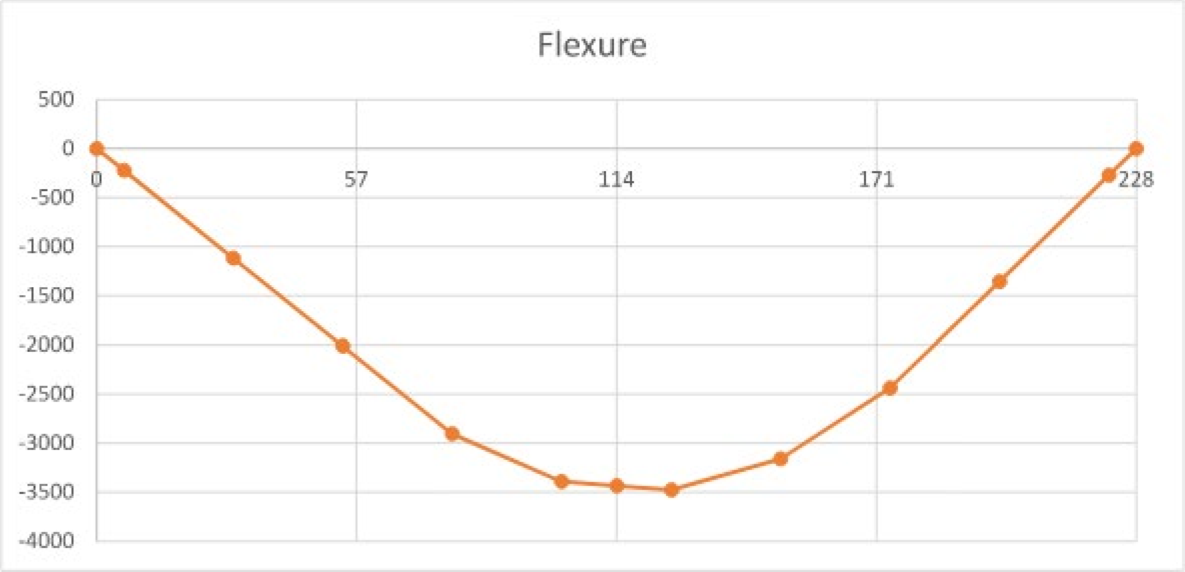
IDEALIZED LOAD DIAGRAM



NOTES:

$M_{mid\ spa}$





Test and Stage Detail

Mn = 2868 k-in

Vn = 53.6 kip

M_{proof} = 2495 k-in

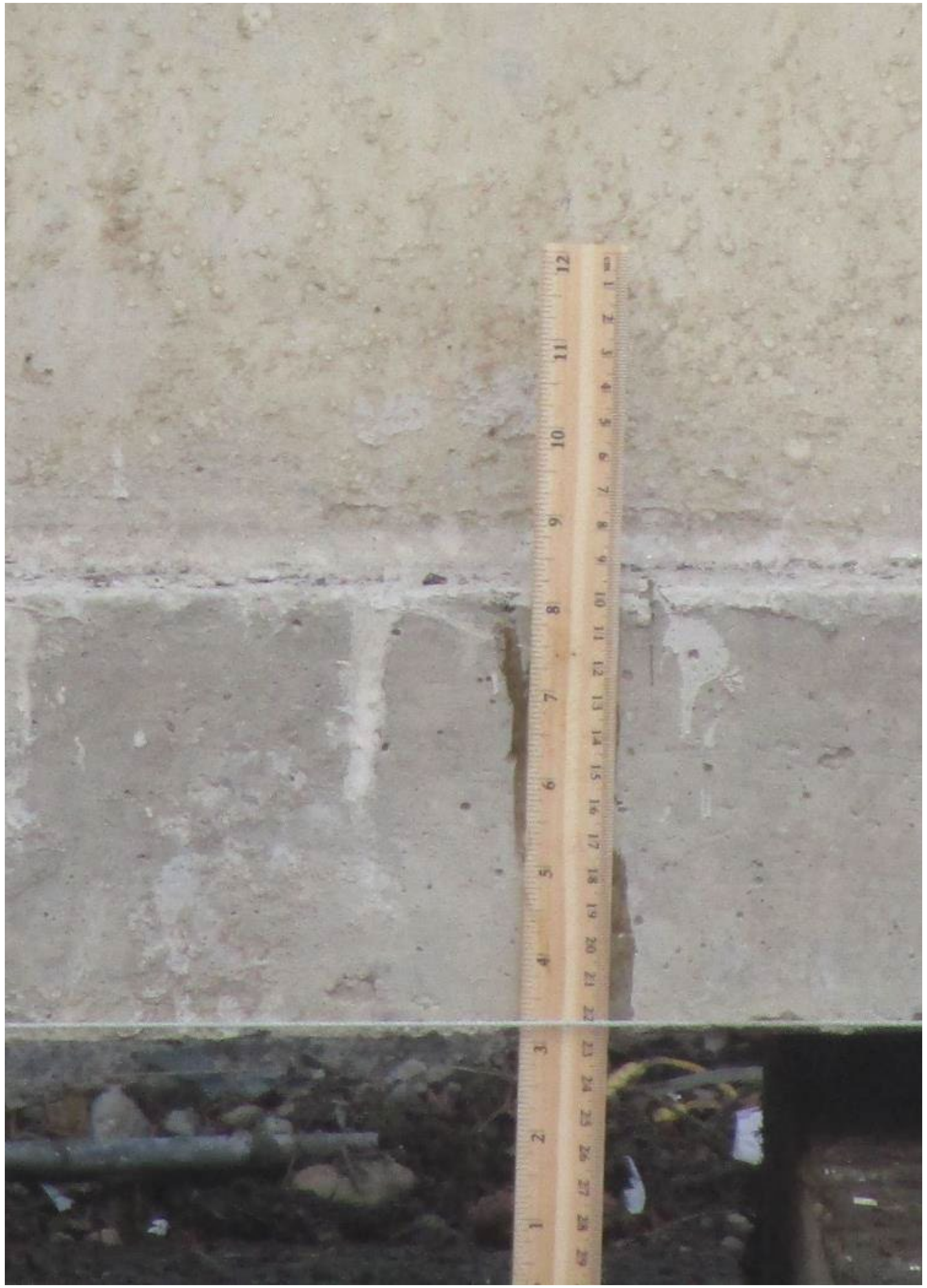
V_{proof} = 42 kip

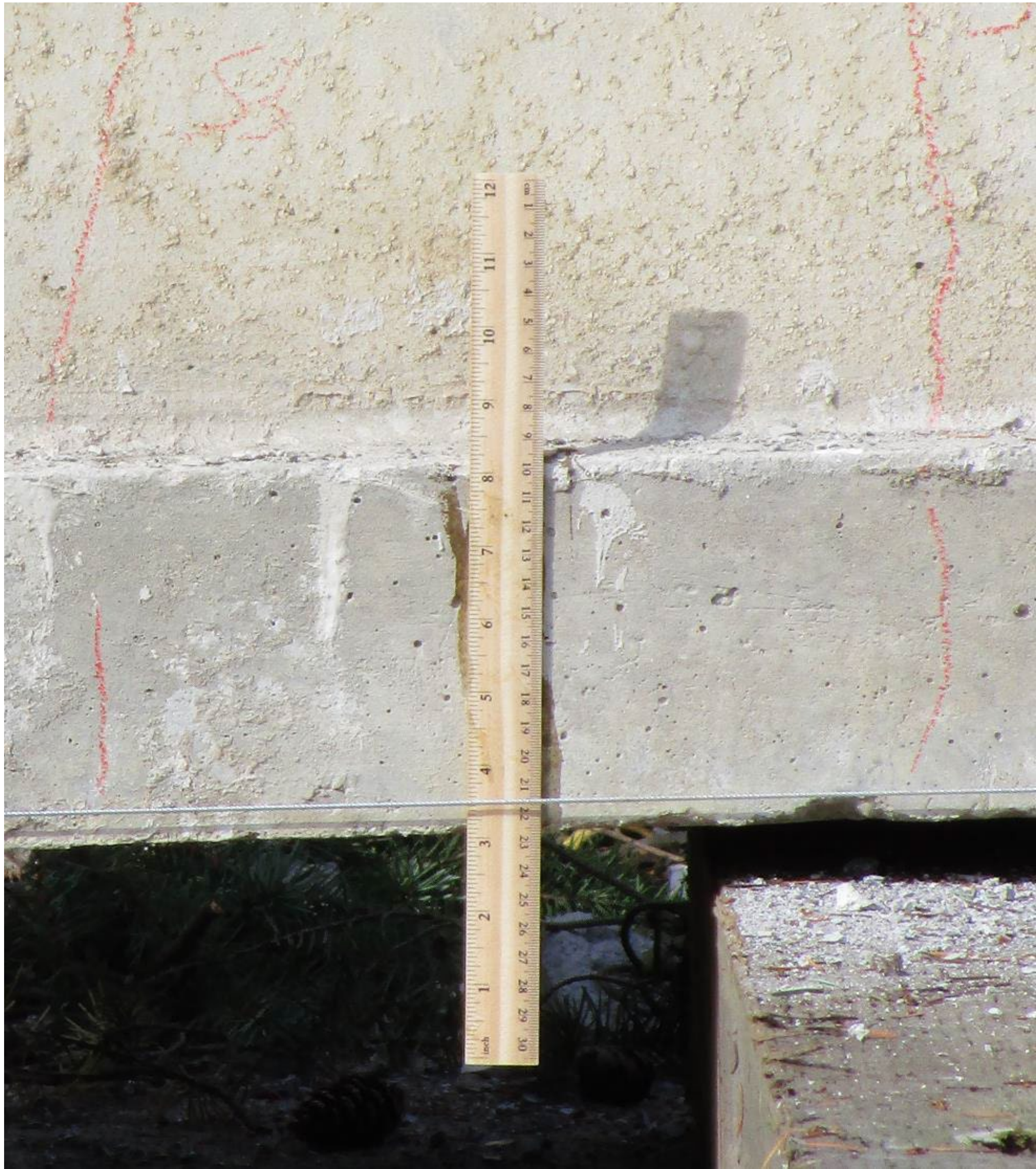
Specimen #:	20-B
Span Length:	20'-0"
Protocol:	Flexure Proof Load
Stage:	10 (140% of Flexure Proof Load)
blocks:	30 blocks
Applied Weight:	82 k
Total Weight	89 k
Max Moment:	3610.6 k-in
Approx shear @ dv:	52.2k

Unloaded Specimen

- Notes:
  - Smalls vertical cracks near midspan during high loads
  - Small diagonal cracks near end of applied loads

  - All crack closed upon uploading.
  - Minor residual deformation (within measurement precision)





Proof Load Testing

Analyze Results

Select a Test Method → Determine a Proof Load → Develop a Protocol → Conduct Test → **Analyze Results**

Results Summary

- All 4 tests exceeded the proof load four flexure and shear
- No test resulted in a failed beam
- No test was terminated due to distress in the beam.
- The resulting load factors for the tested beams area above 1.0

Table 6 Maximum Applied Proof Loads

Test number	Girder Length	Target Proof Load	Max Applied Flexure	Max Applied Shear
#20B	20'-0"	2,495 k-in, 42 kip	3,610 k-in	52.17 k
#20D	20'-0"	2,495 k-in, 42 kip	3,528 k-in	46.25 k
#16A	15'-9"	1,694 k-in, 33 kip	2,730 k-in	43.8 k
#16B	15'-9"	1,694 k-in, 33 kip	2,765 k-in	43.2 k

Capacity and Rating

$$OP = \frac{k_o L_p}{X_{pA}} = \frac{(1.0)(52.17)}{1.61} = 32.40\text{kip}$$

$$RF_0 = \frac{OP}{L_R(1+IM)} = \frac{k_o L_p}{X_{pA}(1+IM)} = \frac{32.40}{20 * (1.33)} = 1.22$$

Table 8.8.3.3.1-1—Adjustments to X_p

Consideration	Adjustment
One-Lane Load Controls	+15%
Nonredundant Structure	+10%
Fracture-Critical Details Present	+10%
Bridges in Poor Condition	+10%
In-Depth Inspection Performed	−5%
Rateable, Existing $RF \geq 1.0$	−5%
$ADTT \leq 1{,}000$	−10%
$ADTT \leq 100$	−15%

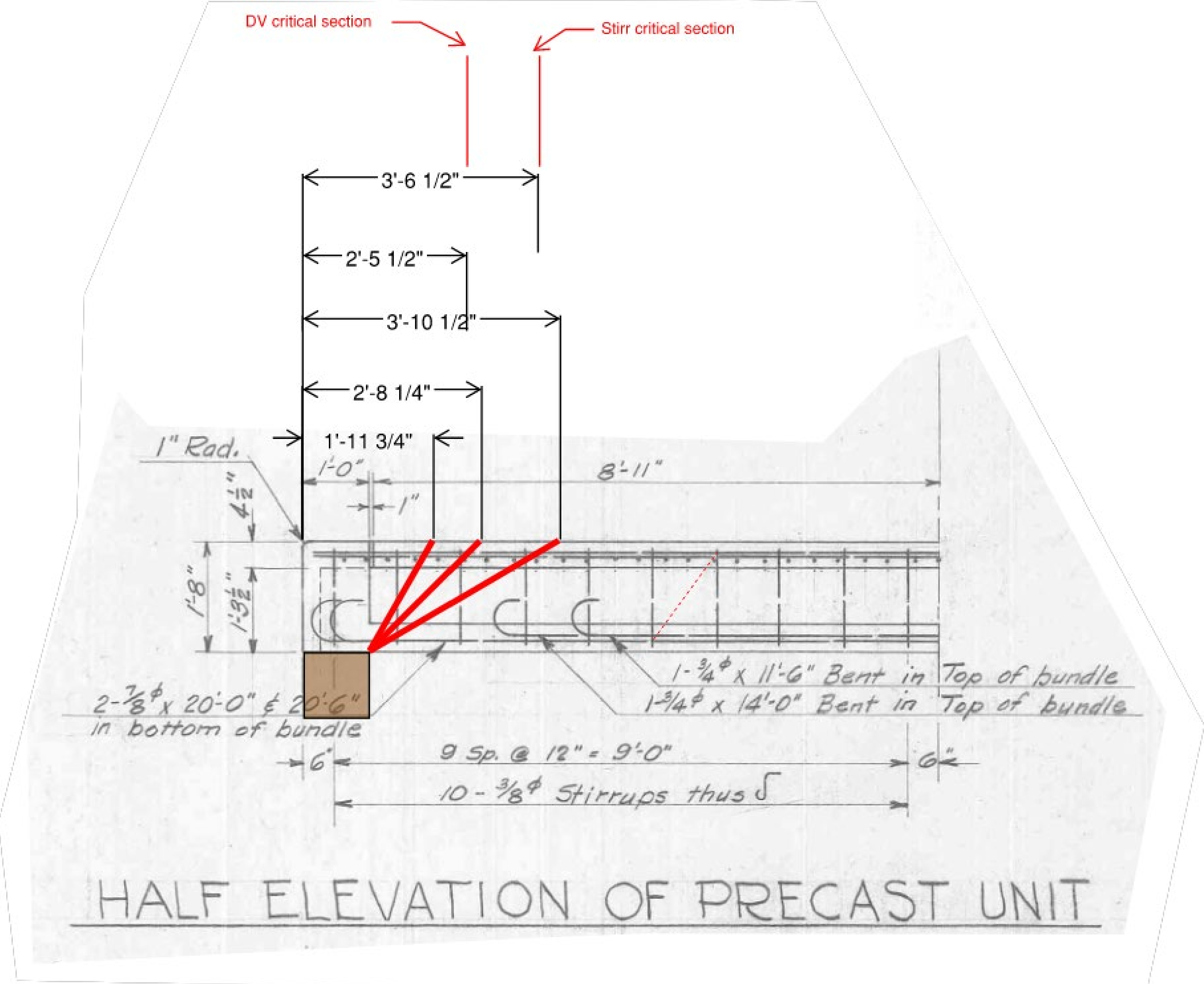
Short Span Channel Bridges

- Application to wider bridge inventory?
  - Channel bridges were all built within a 20 month window
  - Performance of these bridges over their lifespan has been adequate and bridges remain in fair to satisfactory condition.
  - Rating factors for in-service bridges were adjusted from proof load tests based on the following factors.
    - 0.9 – proof load uncertainty factor
    - Variations in HMA overlay depth (field measured vs design)
    - Superstructure condition

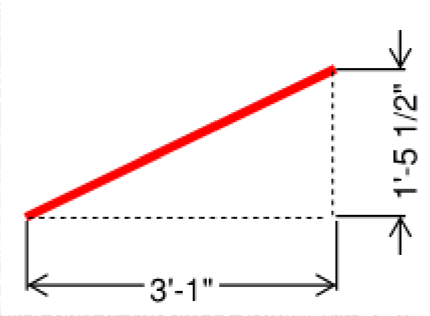
Br No.	Bridge Name	Age	ADT	Percent Trucks	Span	**Cond. Code**
240A	Cottage Lake Creek Bridge	72	14,759	4%	20'	5
3097	Dorre Don Way Bridge	74	95	1%	20'	5
3099	Maxwell Road Bridge	72	520	0%	20'	6
228F	312th AVE SE Bridge	73	798	2%	20'	5
249C	C.W.Neal Bridge	72	99	2%	20'	6
578A	Evans Creek	73	170	5%	20'	5
916A	Pleasant Hill Rd	72	798	2%	20'	5
333A	Bear Creek Bridge	73	8,521	7%	20'	6
480A	Bear Creek Bridge	72	2,200	4%	20'	6
249B	C W Neal Road Bridge	72	99	3%	15.75'	5
909B	Clough Creek Bridge	72	1,328	3%	15.75'	5
3030	SE 380 St Bridge	73	760	2%	15.75'	6
3060	208th Ave SE Bridge	72	150	1%	15.75'	6
593C	May Creek Bridge	72	3717	5%	15.75'	5
1086B	Coal Creek Bridge	73	459	1%	15.75'	5

Questions?

Why???

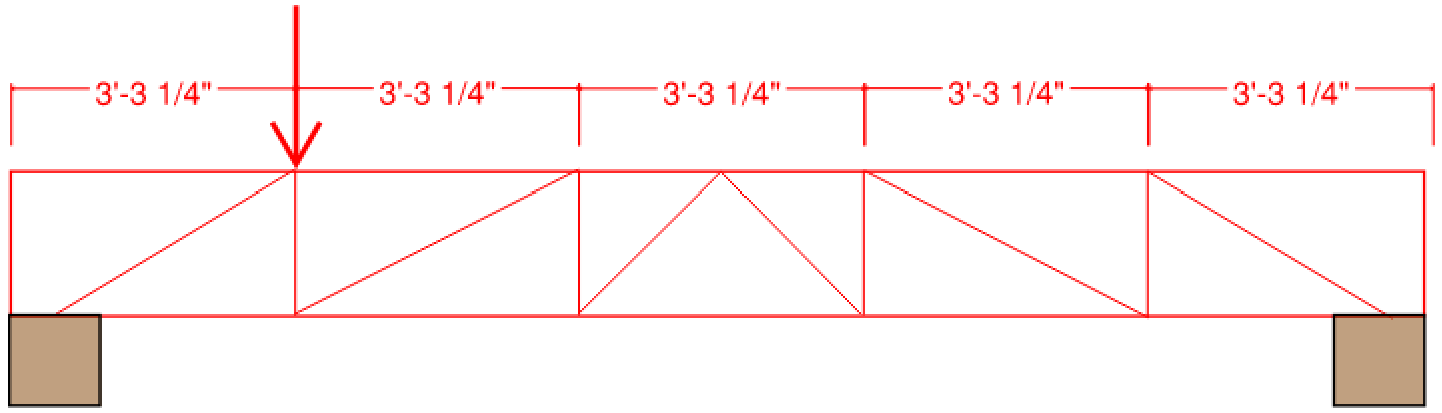


Compression Strut vs Sectional Analysis



- 25 degree strut angle for STM

Why???



Compression Strut vs Sectional Analysis

- 25 degree strut angle for STM