

**METHODS FOR STRENGTHENING
REINFORCED CONCRETE BRIDGE
GIRDERS CONTAINING POORLY
DETAILED FLEXURAL STEEL USING
NEAR-SURFACE MOUNTED
METALLICS
Final Report Appendices A**

SPR 750



Oregon Department of Transportation

APPENDIX A

EXPERIMENTAL DATA for IT SPECIMENS

APPENDIX A: EXPERIMENTAL DATA FOR IT SPECIMENS

Appendix A details the instrumentation types and labels for each of the test specimens. The purpose of each instrument is described in *Section 3.4*. Plots are provided illustrating the data gathered from testing and calculated tensile forces.

Midspan Displacement: Midspan displacement was measured on both the east and west sides of the beam. Support settlements were measured on all four corners of the specimens at the support centerlines. The average midspan displacement was found by subtracting the average of the support settlements from the average of the midspan displacements.

Cutoff Bar Slip: Sensors were located at the ends of the cutoff bars for specimens IT.45.Ld3(10).Ti, IT.45.Ld3(6).Ti, and IT.45.Ld3(6).SS. Both the west and the east cutoff bar slip were measured.

Diagonal String Potentiometers: Diagonal displacement sensors were used to measure the change in crack widths crossing the sensor. The sensors were anchored to the beam and connected to a brass wire anchored at the opposing diagonal point. The sensors were numbered, with the arrow showing the direction of measurement. The labeling diagrams are shown below in Figures A.1 through A.3.

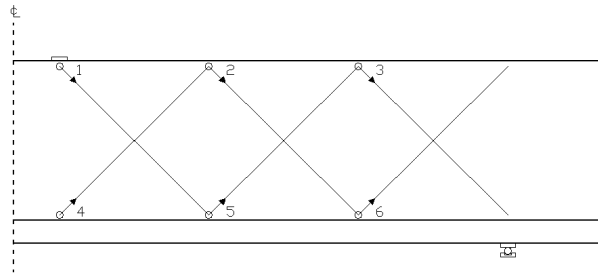


Figure A.1 – Specimens IT.45.Ld3(10).Ti, IT.45.Ld3(6).Ti, and IT.45.Ld3(6).SS north diagonal sensor numbering

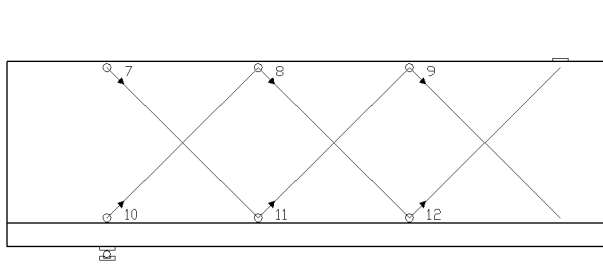


Figure A.2 – Specimens IT.45.Ld3(6).Ti and IT.45.Ld3(6).SS south diagonal sensor numbering

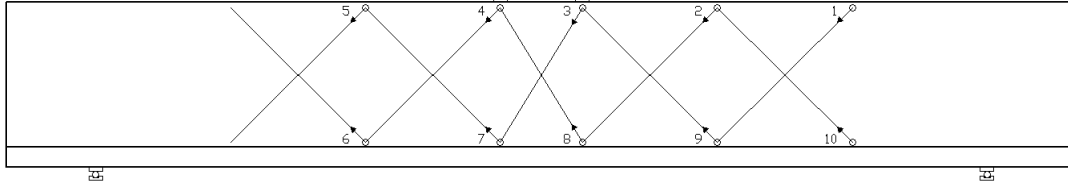


Figure A.3 – Specimen IT.0.0(6).Ti diagonal sensor numbering

Strain Gages: Strain gages were placed on specimens IT.45.Ld3(10).Ti, IT.45.Ld3(6).Ti, and IT.45.Ld3(6).SS along the cutoff bar development length to the preformed crack. Gages were also used around the NSM hook locations. Stirrups had gages at points where they crossed the preformed crack and at mid-height north of the preformed crack. For specimen IT.0.0(6).Ti, gages were placed along the development length of the cut bars and on the titanium at the hook locations. Gages were installed mid-height on stirrups around the titanium hook locations. Figures A.4 through A.7 illustrate the strain gage and section labeling convention for the specimens. The second instrumented titanium bar in specimen IT.45.Ld3(6).Ti was installation backwards, therefore the critical section gages 14-17 are in the incorrect locations. Strains are shown along the beam as measured, but strain data from the first titanium bar were used to represent both bars in the critical section.

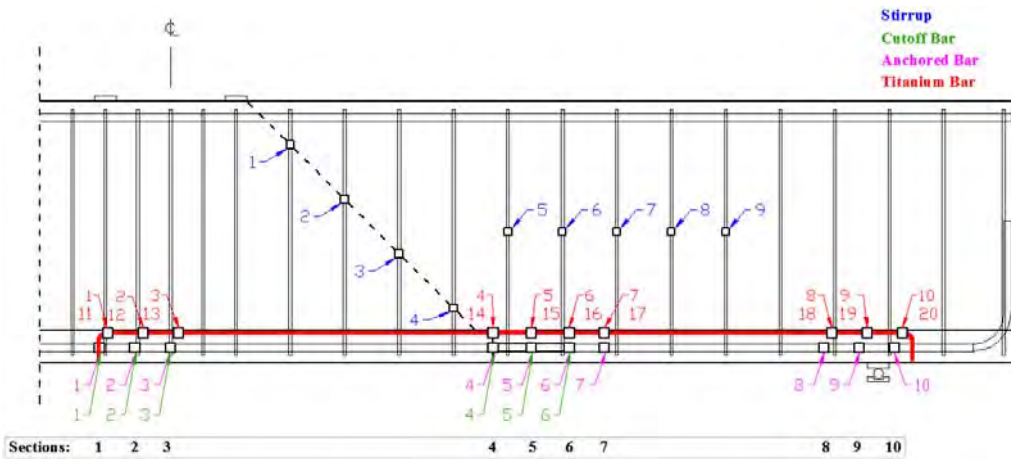


Figure A.4 – Specimen IT.45.Ld3(10).Ti strain gage labeling convention

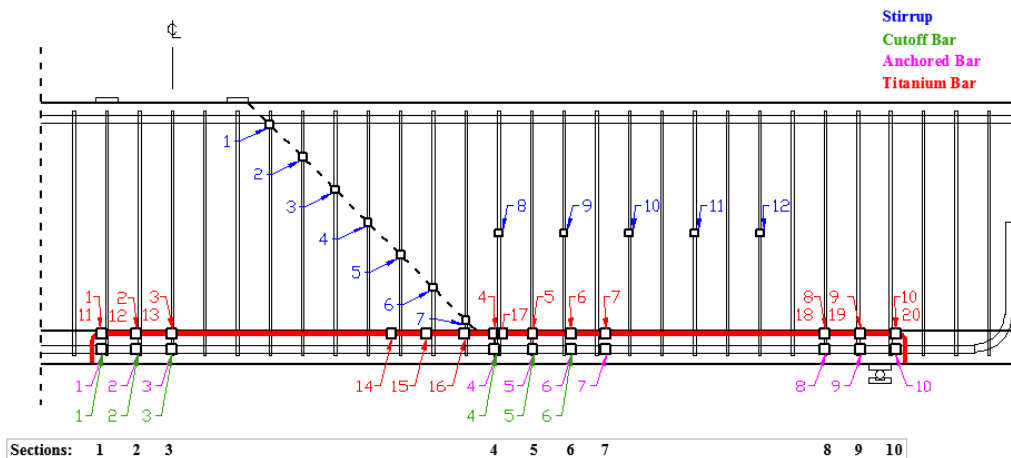


Figure A.5 – Specimen IT.45.Ld3(6).Ti strain gage labeling convention

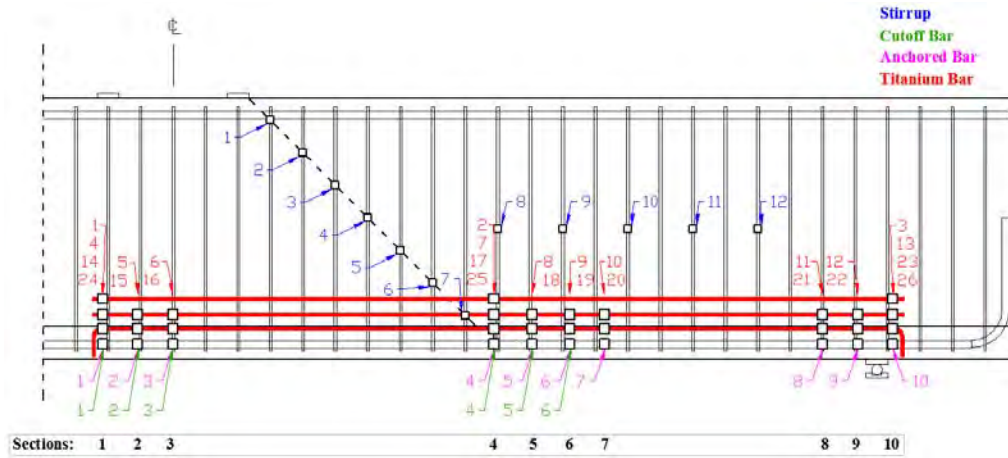


Figure A.6 – Specimen IT.45.Ld3(6).SS strain gage labeling convention

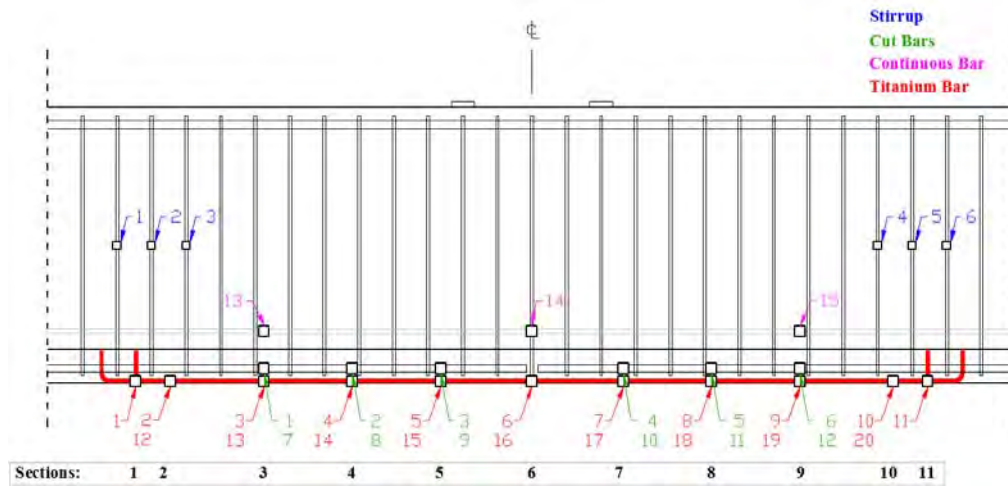


Figure A.7 – Specimen IT.0.0(6).Ti strain gage labeling convention

Figures A.8 through A.103 show the data collected by the instrumentation and the calculated tensile forces.



Figure A.8 – Specimen IT.45.Ld3(10).Ti front and back failure photographs

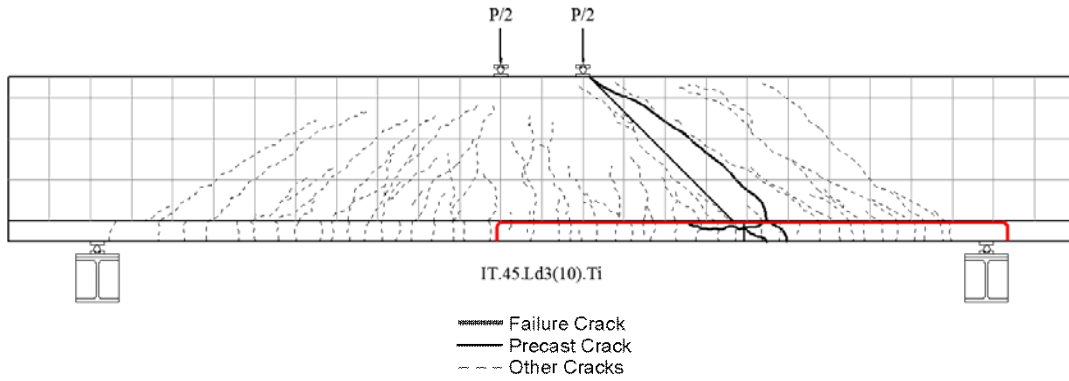


Figure A.9 – Specimen IT.45.Ld3(10).Ti crack mapping with failure cracks

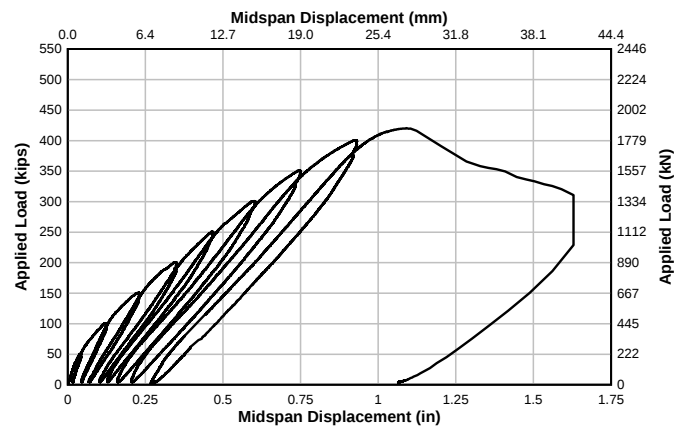


Figure A.10 – Specimen IT.45.Ld3(10).Ti load-displacement response

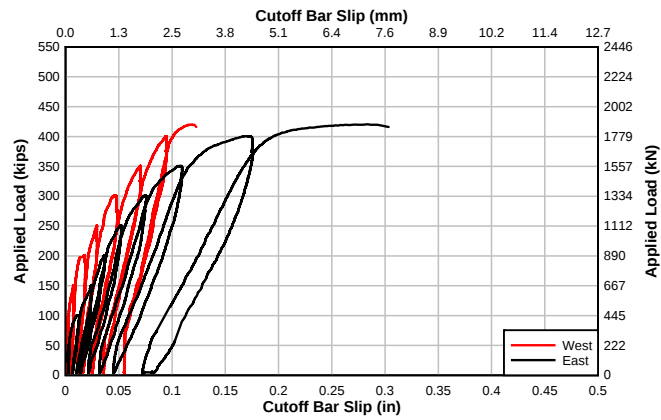


Figure A.11 – Specimen IT.45.Ld3(10).Ti load-cutoff bar slip response

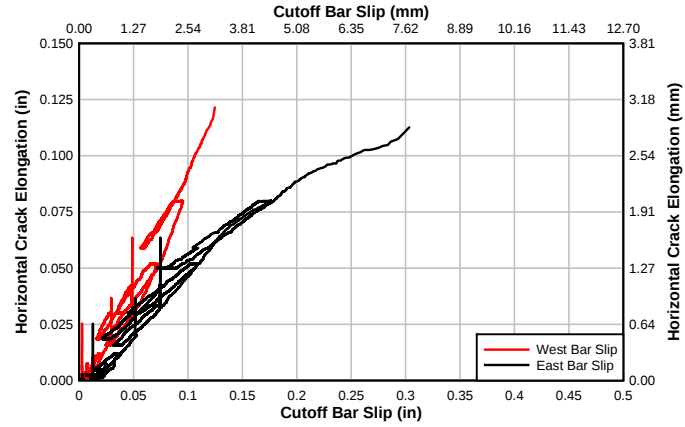


Figure A.12 – Specimen IT.45.Ld3(10).Ti horizontal crack elongation-cutoff bar slip

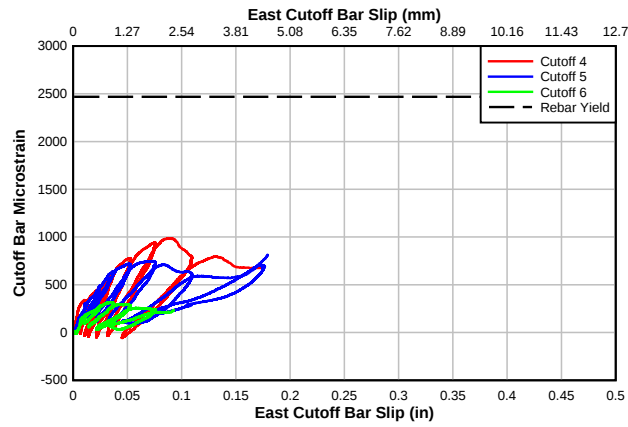


Figure A.13 – Specimen IT.45.Ld3(10).Ti cutoff bar strain-slip

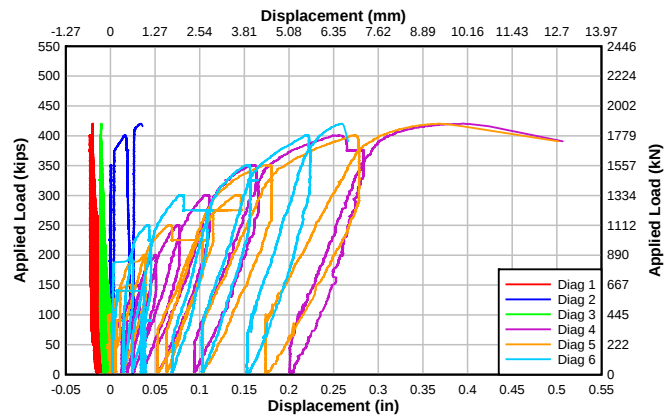


Figure A.14 – Specimen IT.45.Ld3(10).Ti load-diagonal displacement

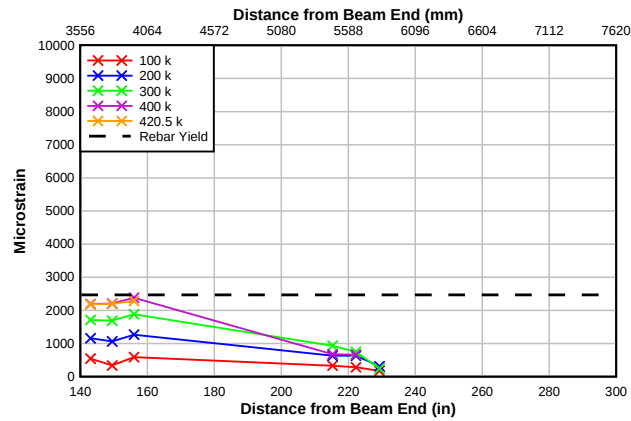


Figure A.15 – Specimen IT.45.Ld3(10).Ti cutoff reinforcing steel strain along specimen length

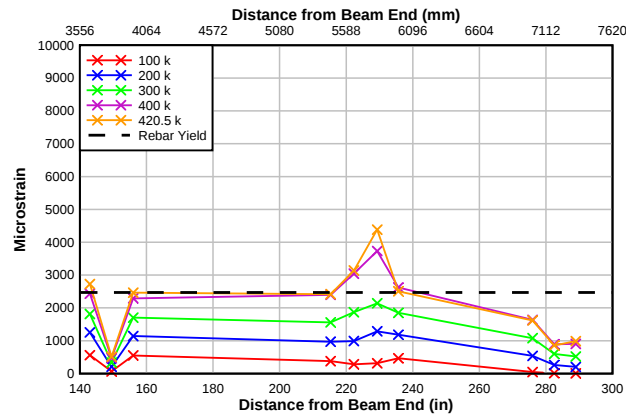


Figure A.16 – Specimen IT.45.Ld3(10).Ti anchored reinforcing steel strain along specimen length

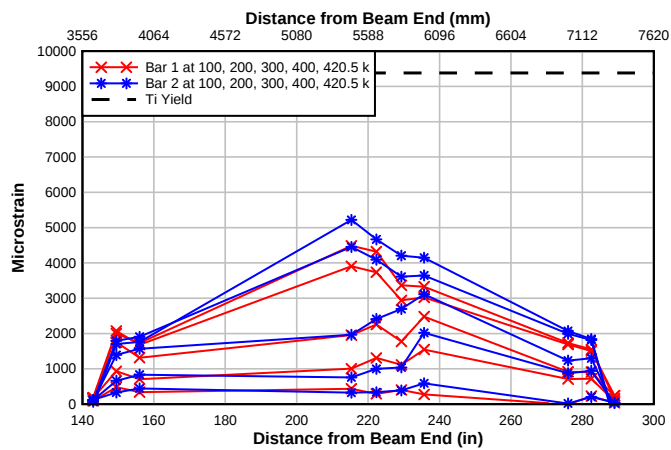


Figure A.17 – Specimen IT.45.Ld3(10).Ti titanium bar strain along specimen length

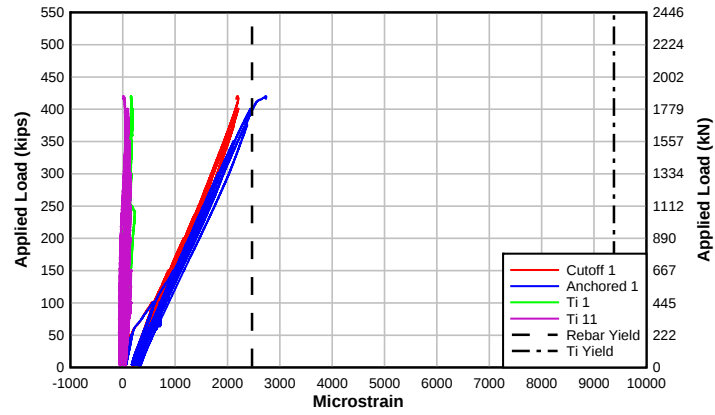


Figure A.18 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 1)

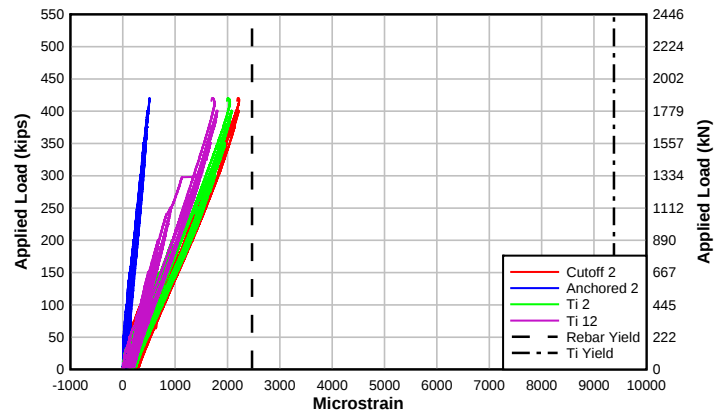


Figure A.19 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 2)

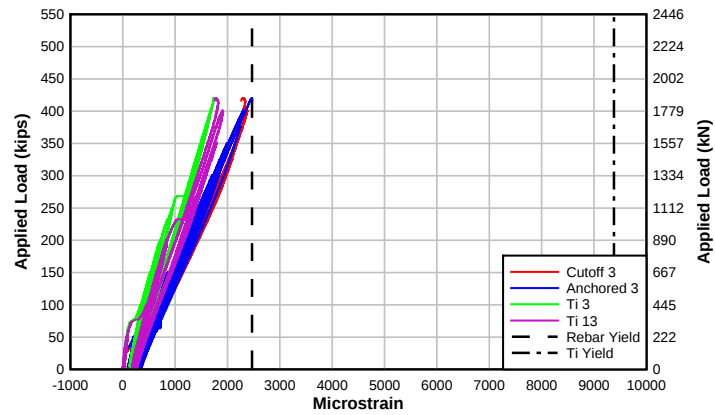


Figure A.20 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 3)

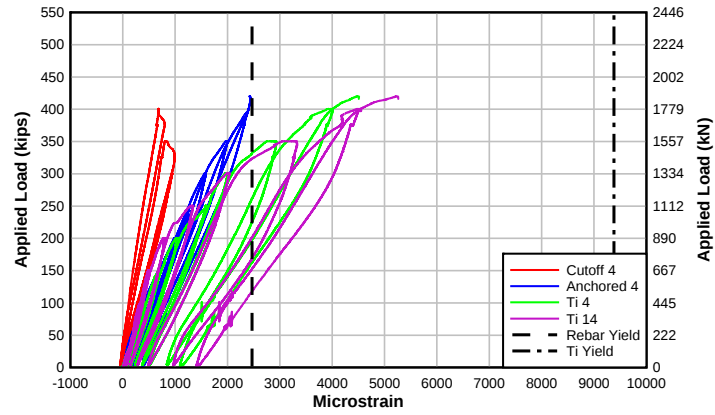


Figure A.21 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 4)

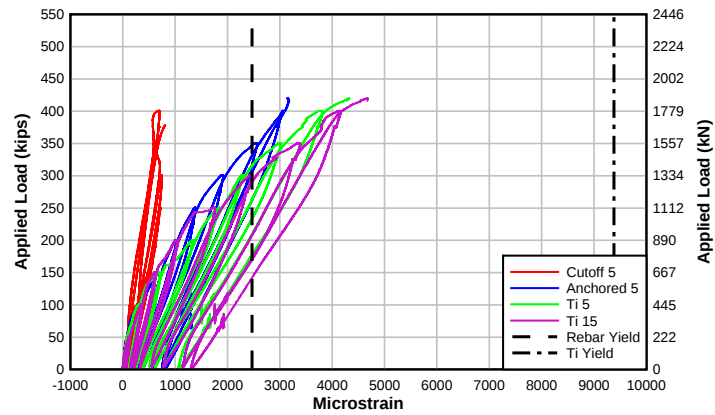


Figure A.22 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 5)

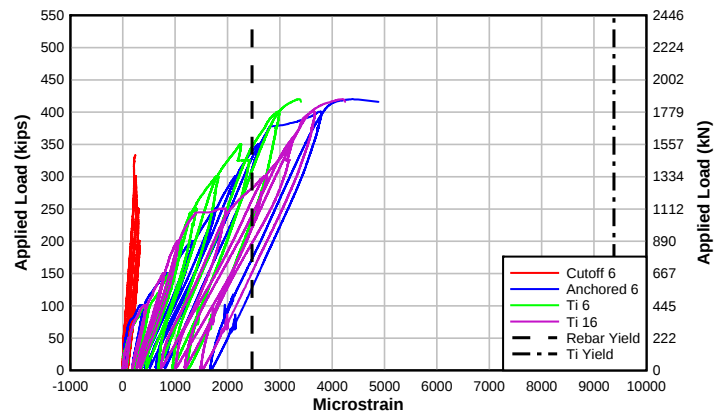


Figure A.23 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 6)

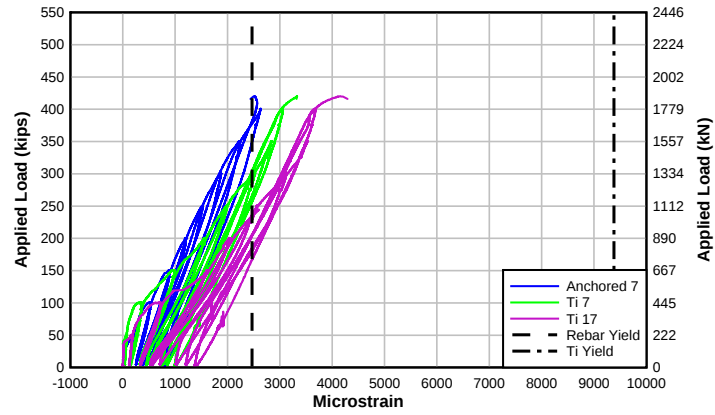


Figure A.24 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 7)

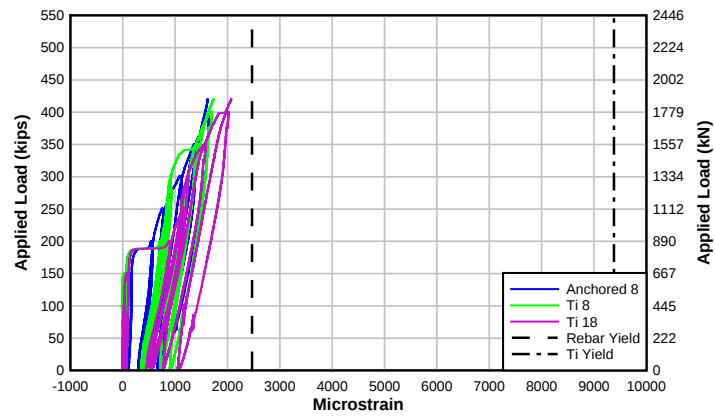


Figure A.25 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 8)

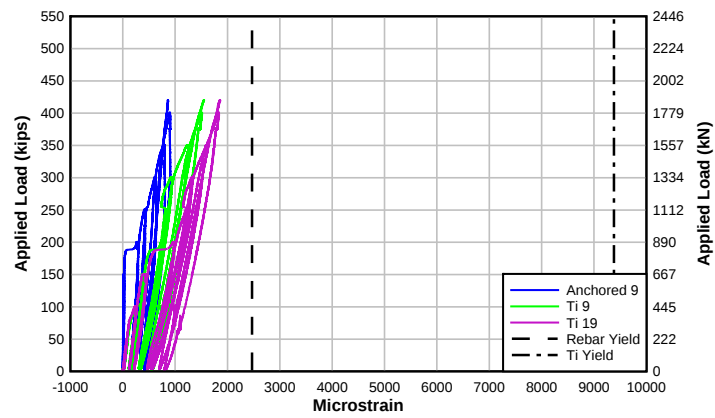


Figure A.26 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 9)

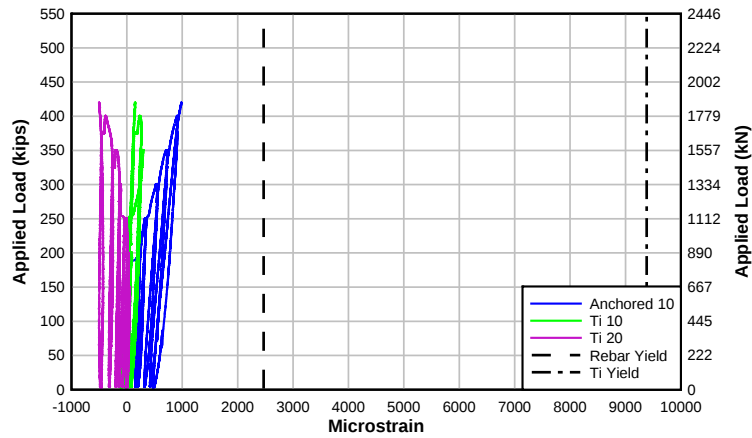


Figure A.27 – Specimen IT.45.Ld3(10).Ti load-flexural bar strain (Section 10)

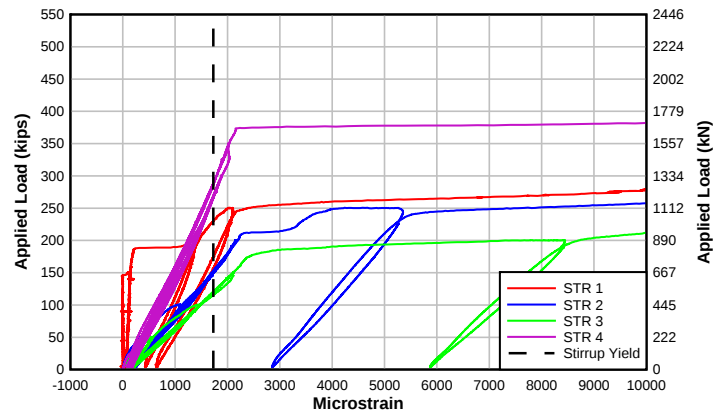


Figure A.28 – Specimen IT.45.Ld3(10).Ti load-preformed crack stirrup strain

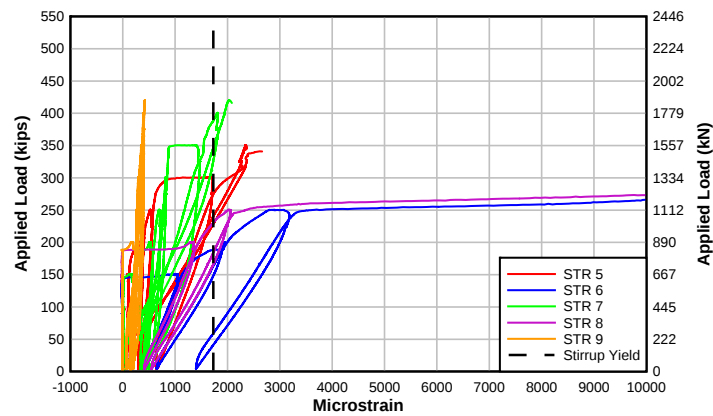


Figure A.29 – Specimen IT.45.Ld3(10).Ti load-mid-height stirrup strain

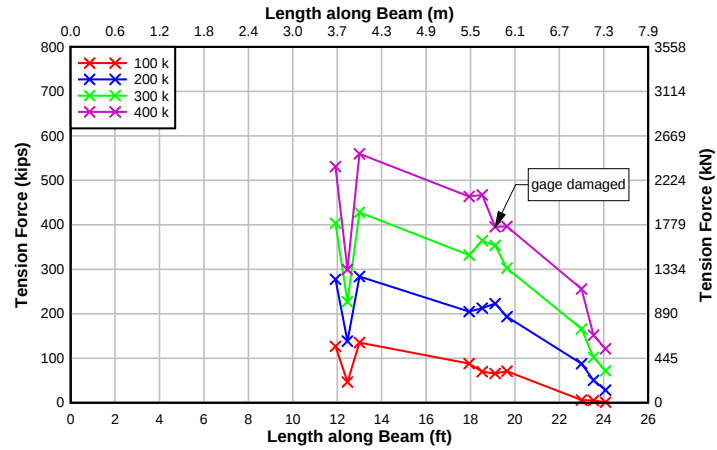


Figure A.30 – Specimen IT.45.Ld3(10) tension force in all flexural tension reinforcement along beam

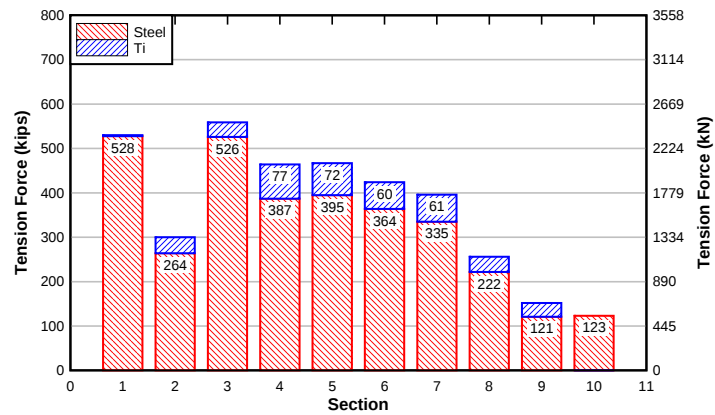


Figure A.31 – Specimen IT.45.Ld3(10).Ti tension force contribution-section at 400 kips (1780 kN)



Figure A.32 – Specimen IT.45.Ld3(6).Ti front and back failure photographs

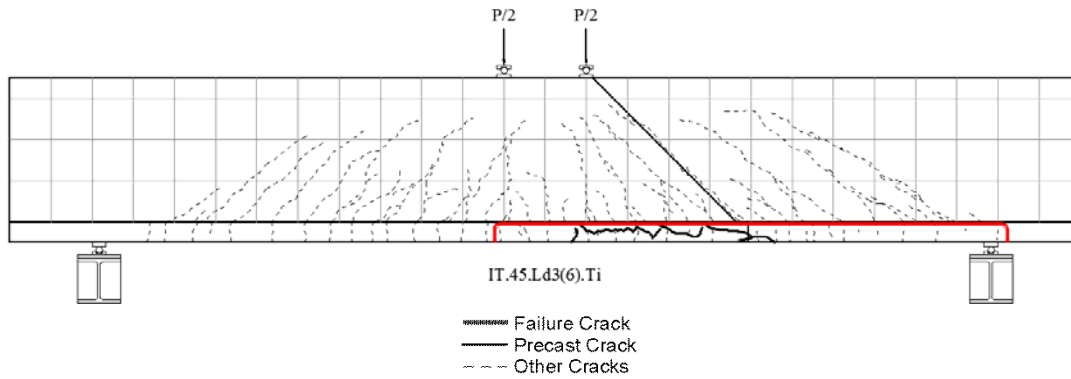


Figure A.33 – Specimen IT.45.Ld3(6).Ti crack mapping with failure cracks

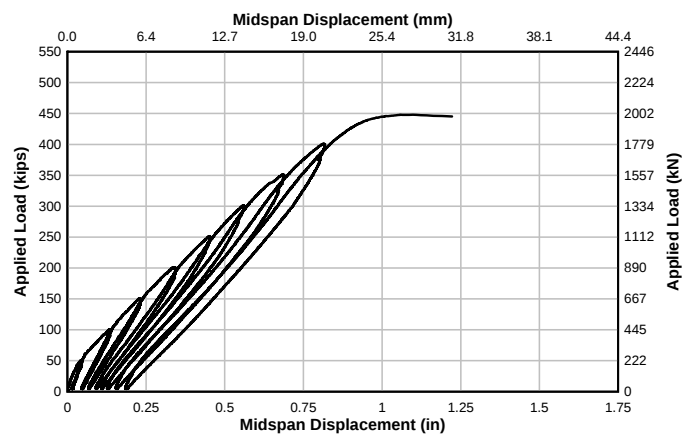


Figure A.34 – Specimen IT.45.Ld3(6).Ti load-displacement response

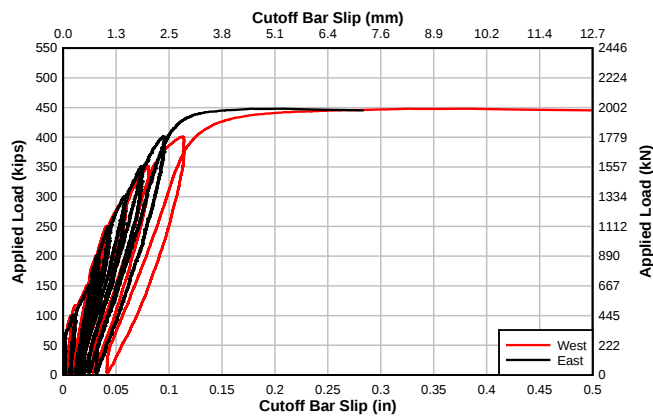


Figure A.35 – Specimen IT.45.Ld3(6).Ti load-cutoff bar slip response

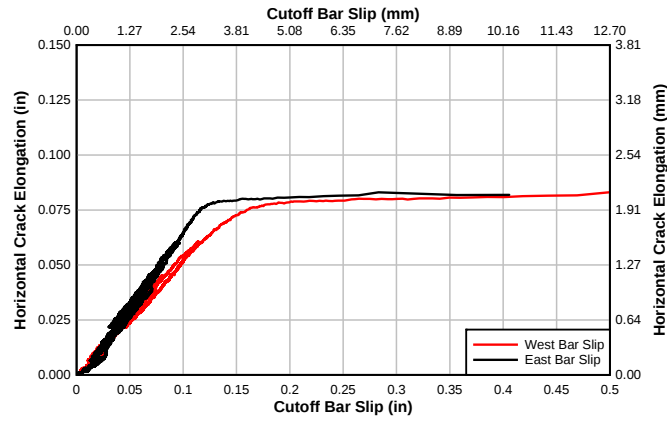


Figure A.36 – Specimen IT.45.Ld3(6).Ti horizontal crack elongation-cutoff bar slip

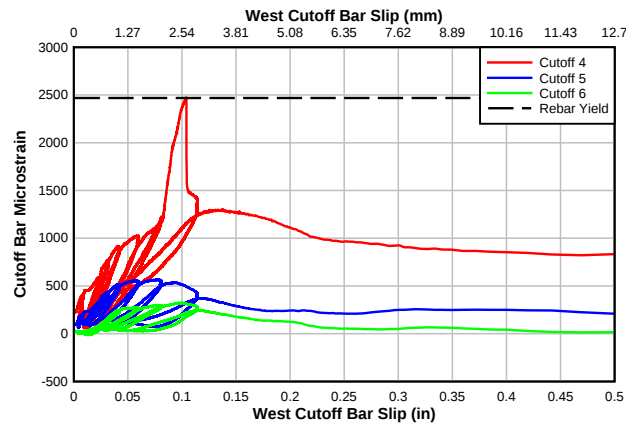


Figure A.37 – Specimen IT.45.Ld3(6).Ti cutoff bar strain-slip

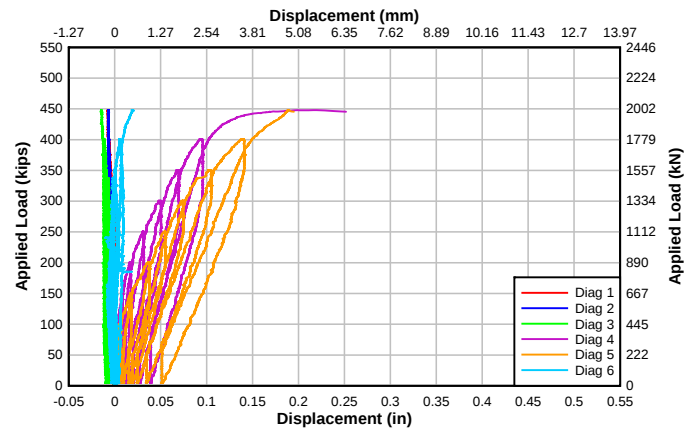


Figure A.38 – Specimen IT.45.Ld3(6).Ti load-diagonal displacement (north)

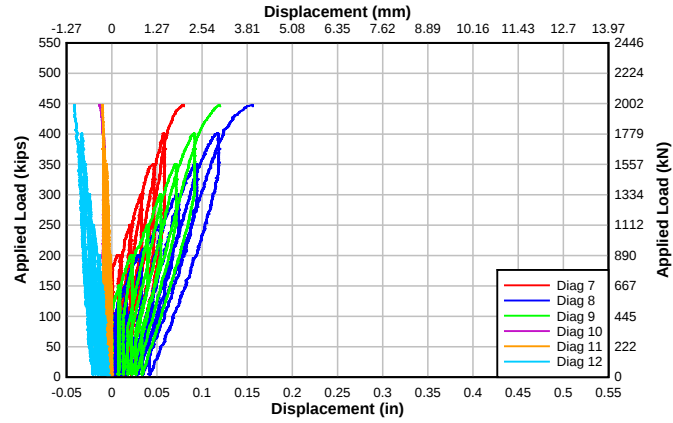


Figure A.39 – Specimen IT.45.Ld3(6).Ti load-diagonal displacement (south)

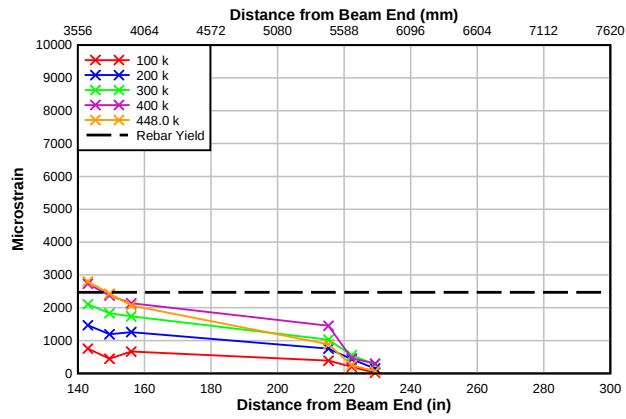


Figure A.40 – Specimen IT.45.Ld3(6).Ti cutoff reinforcing steel strain along specimen length

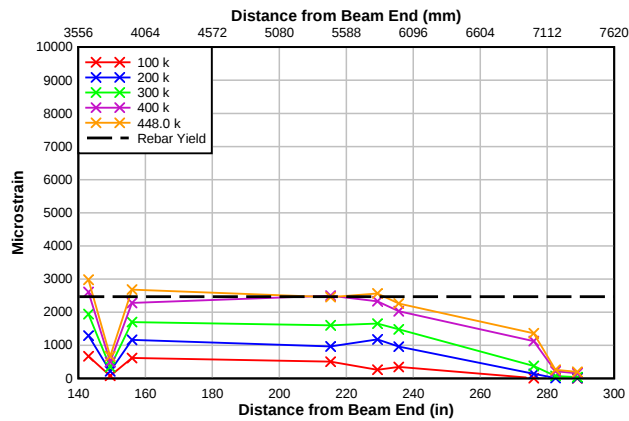


Figure A.41 – Specimen IT.45.Ld3(6).Ti anchored reinforcing steel strain along specimen length

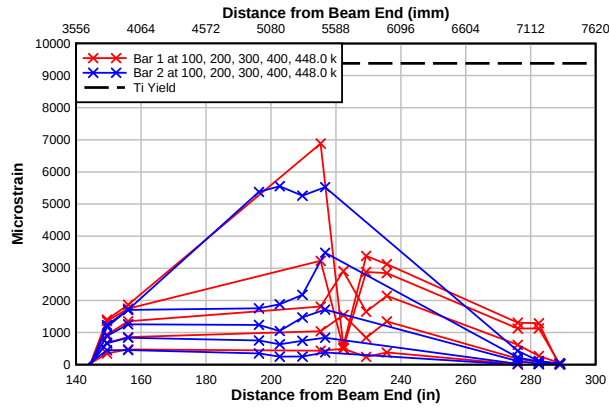


Figure A.42 – Specimen IT.45.Ld3(6).Ti titanium bar strain along specimen length

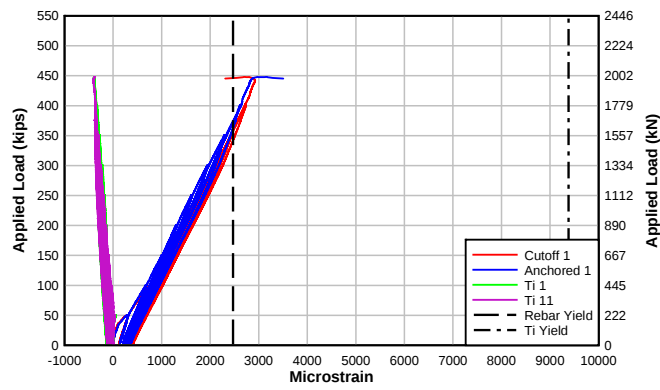


Figure A.43 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 1)

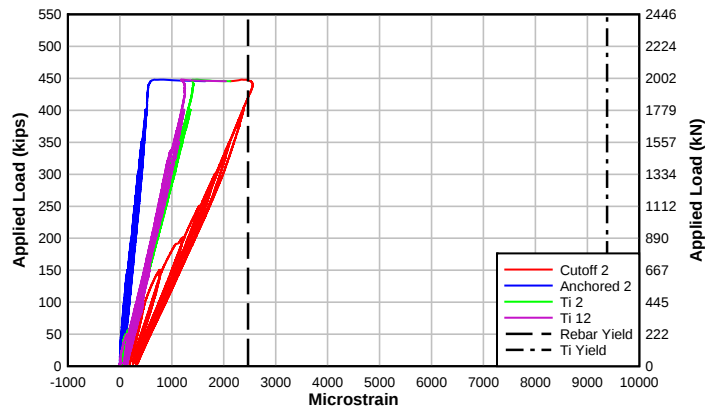


Figure A.44 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 2)

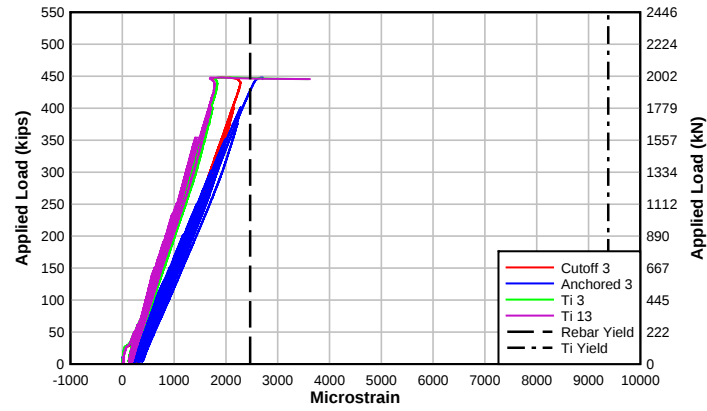


Figure A.45 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 3)

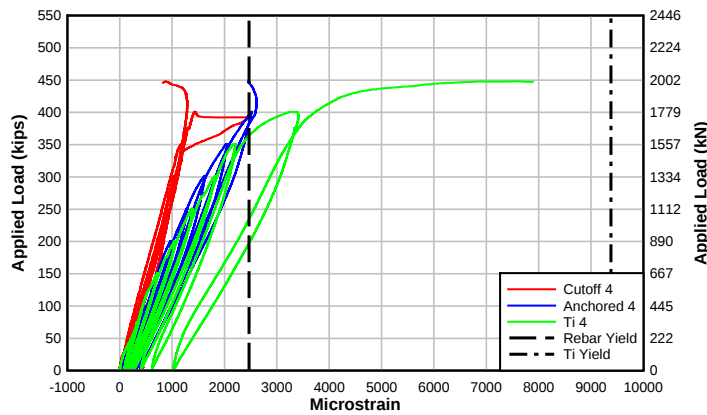


Figure A.46 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 4)

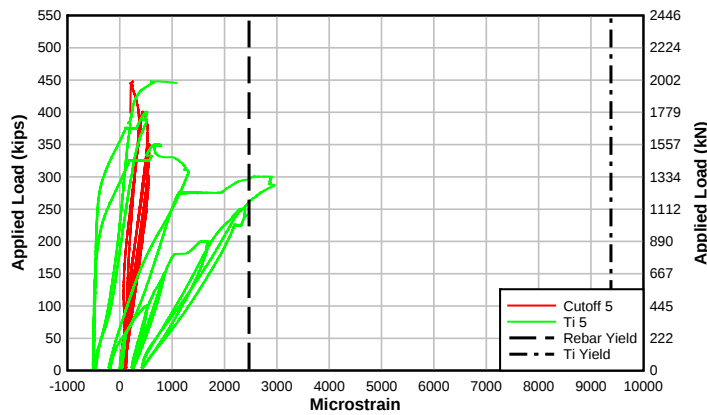


Figure A.47 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 5)

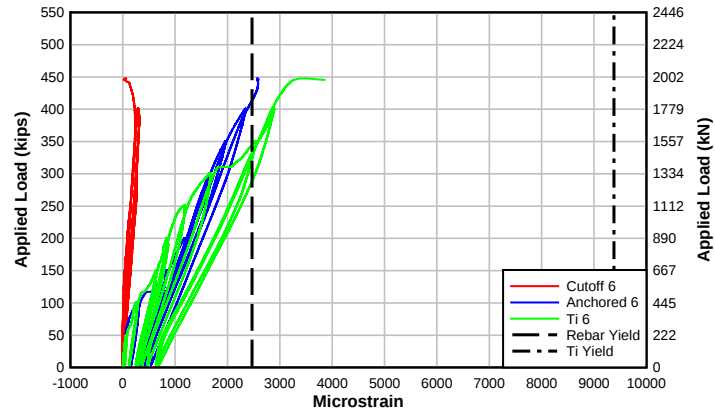


Figure A.48 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 6)

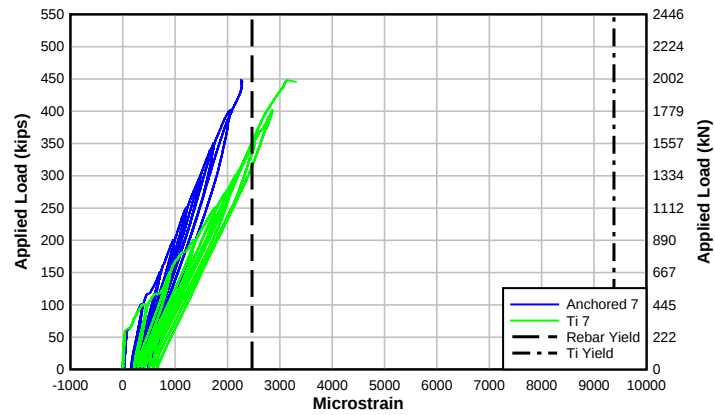


Figure A.49 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 7)

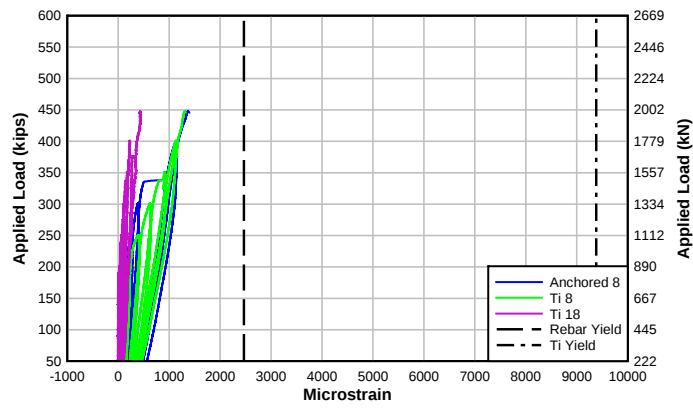


Figure A.50 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 8)

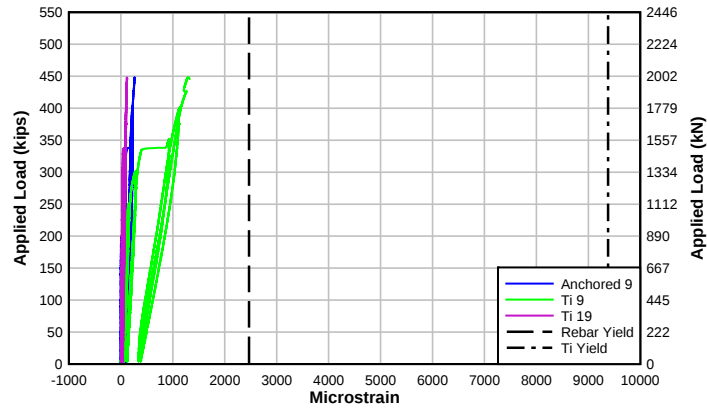


Figure A.51 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 9)

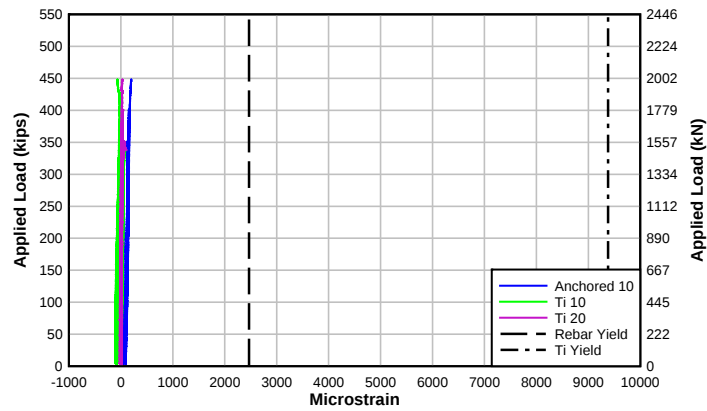


Figure A.52 – Specimen IT.45.Ld3(6).Ti load-flexural bar strain (Section 10)

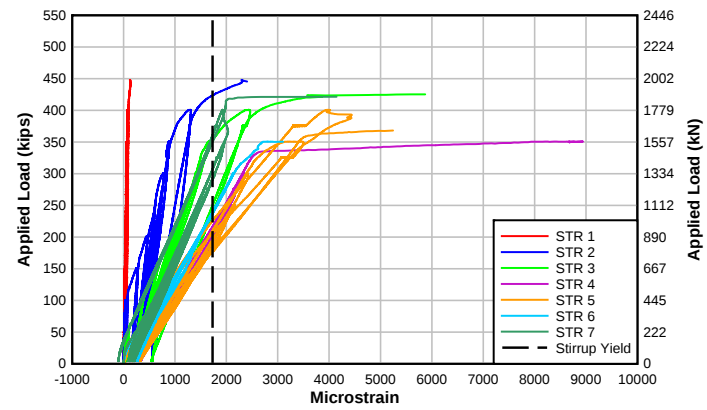


Figure A.53 – Specimen IT.45.Ld3(6).Ti load-preformed crack stirrup strain

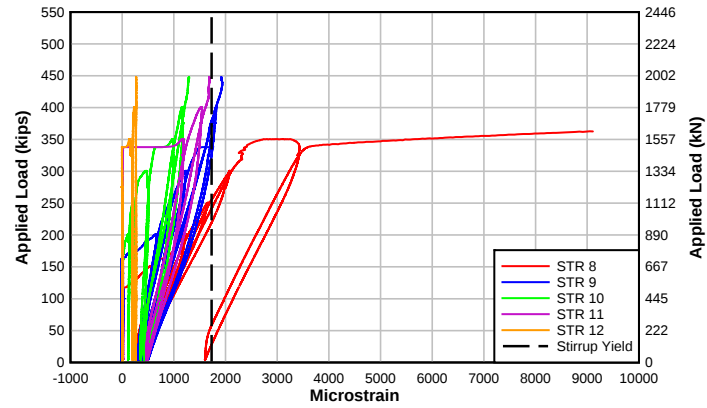


Figure A.54 – Specimen IT.45.Ld3(6).Ti load-mid-height stirrup strain

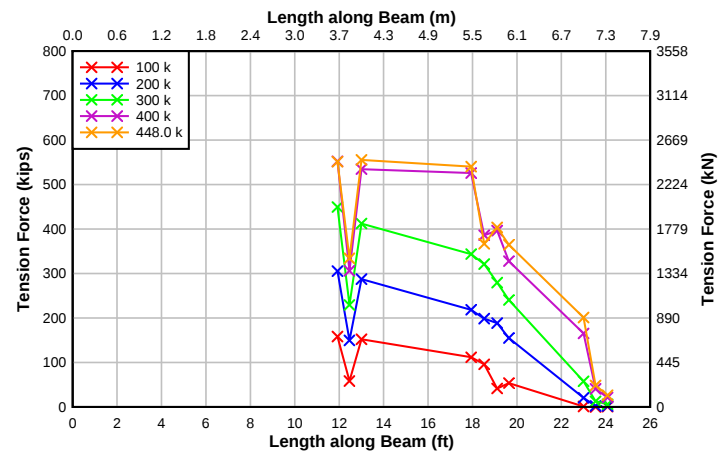


Figure A.55 – Specimen IT.45.Ld3(6).Ti tension force in all flexural tension reinforcement along beam

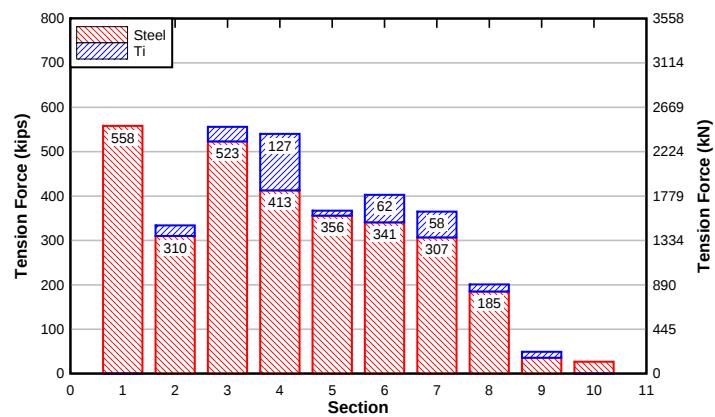


Figure A.56 – Specimen IT.45.Ld3(6).Ti tension force contribution-section at failure



Figure A.57 – Specimen IT.45.Ld3(6).SS front and back failure photographs

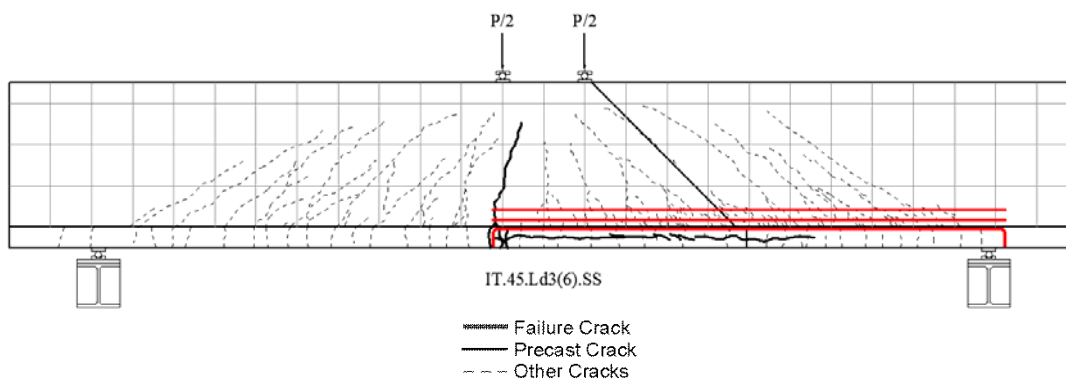


Figure A.58 – Specimen It.45.Ld3(6).SS crack mapping with failure cracks

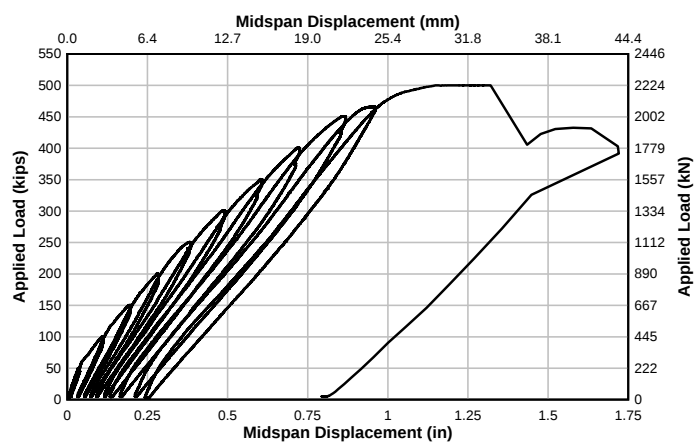


Figure A.59 – Specimen IT.45.Ld3(6).SS load-displacement response

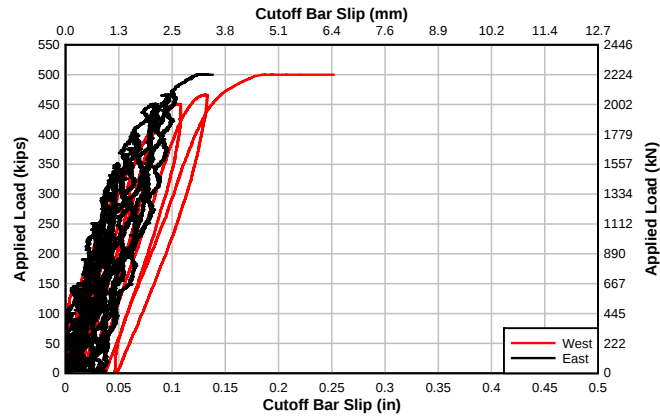


Figure A.60 – Specimen IT.45.Ld3(6).SS load-cutoff bar slip response

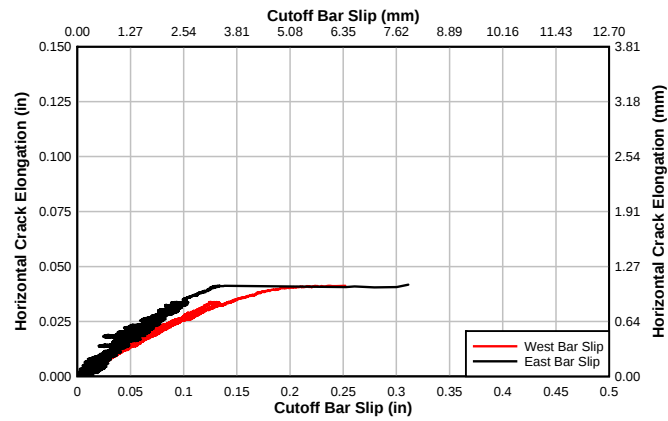


Figure A.61 – Specimen IT.45.Ld3(6).SS horizontal crack elongation-cutoff bar slip

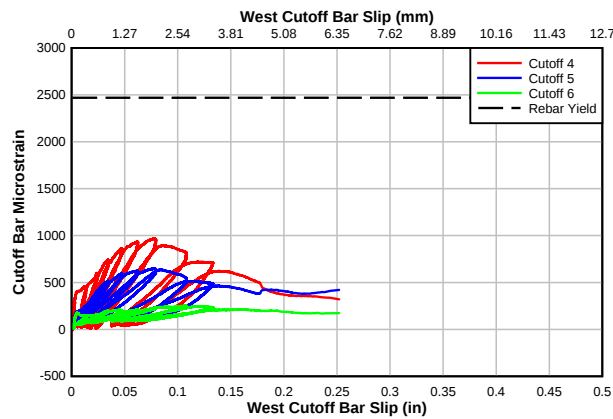


Figure A.62 – Specimen IT.45.Ld3(6).SS cutoff bar strain-slip

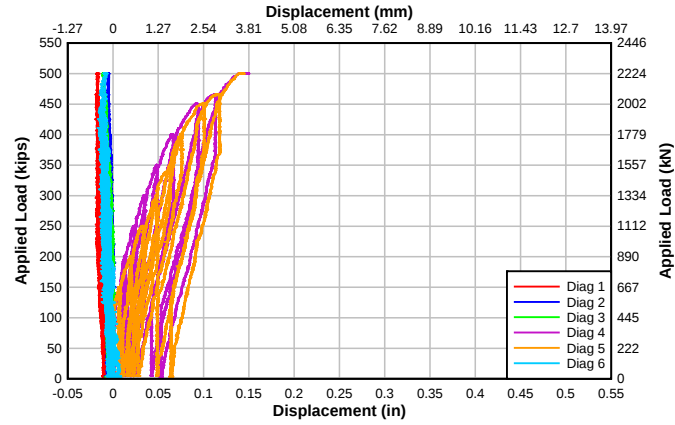


Figure A.63 – Specimen IT.45.Ld3(6).SS load-diagonal displacement (north)

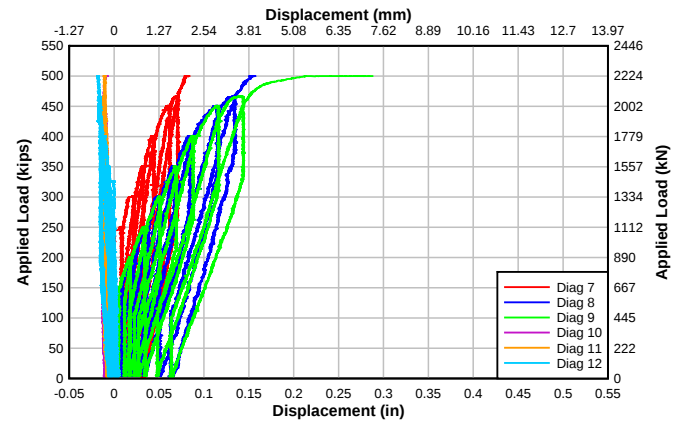


Figure A.64 – Specimen IT.45.Ld3(6).SS load-diagonal displacement (south)

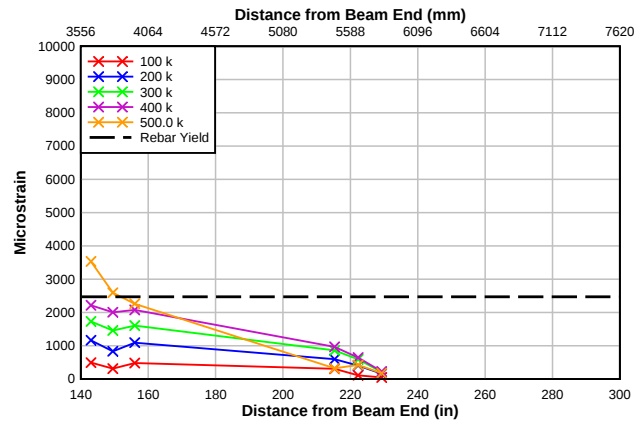


Figure A.65 – Specimen IT.45.Ld3(6).SS cutoff reinforcing steel strain along specimen length

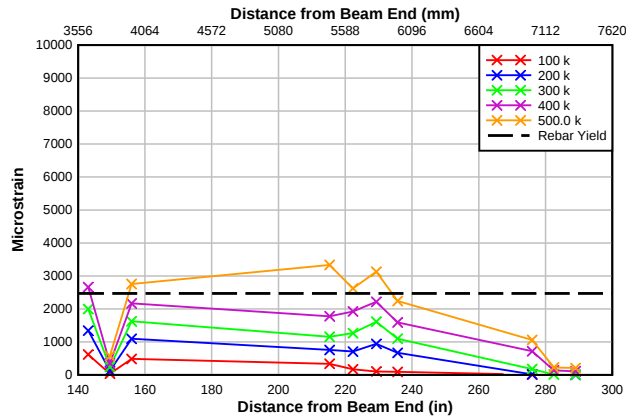


Figure A.66 – Specimen IT.45.Ld3(6).SS anchored reinforcing steel strain along specimen length

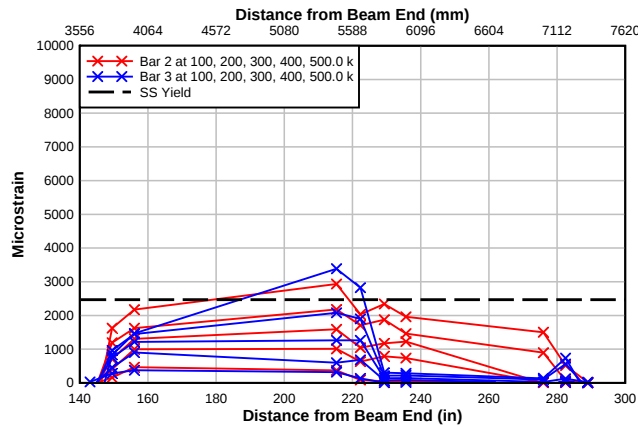


Figure A.67 – Specimen IT.45.Ld3(6).SS stainless steel strain along specimen length

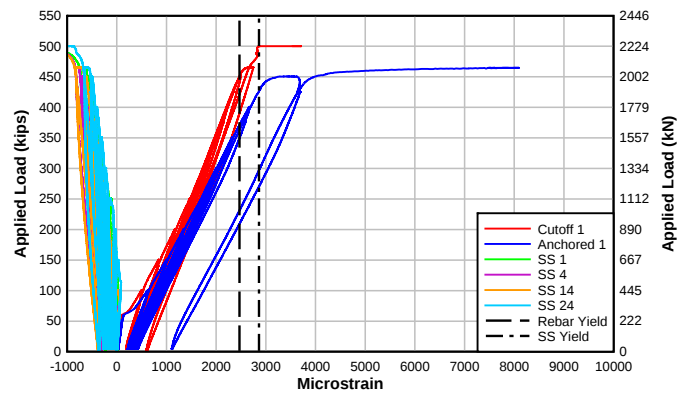


Figure A.68 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 1)

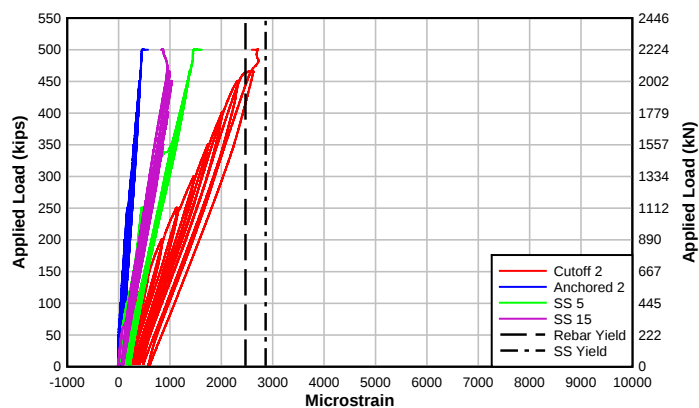


Figure A.69 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 2)

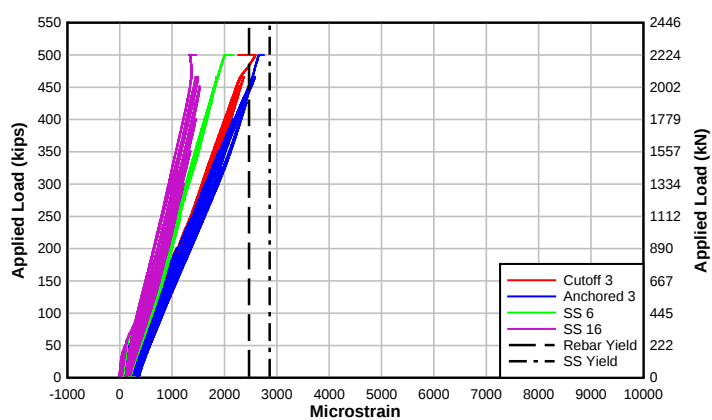


Figure A.70 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 3)

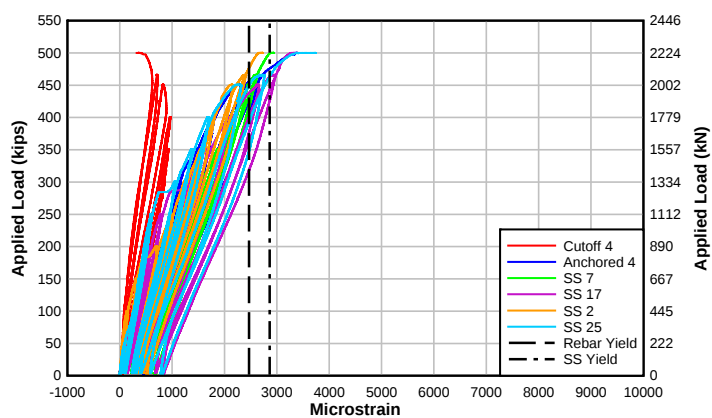


Figure A.71 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 4)

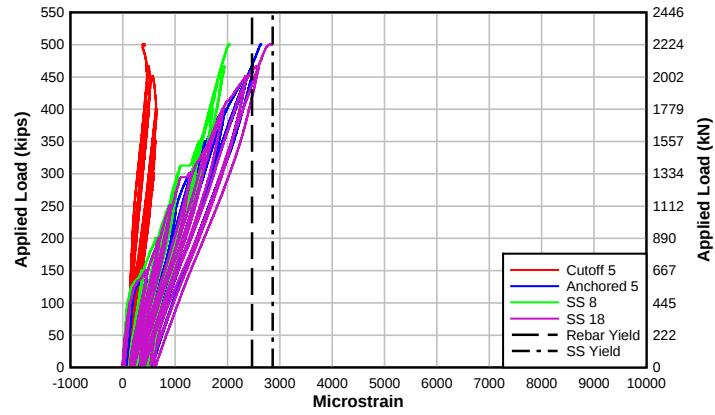


Figure A.72 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 5)

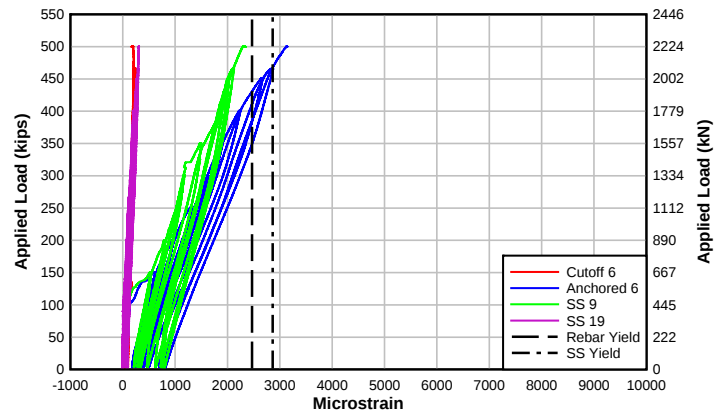


Figure A.73 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 6)

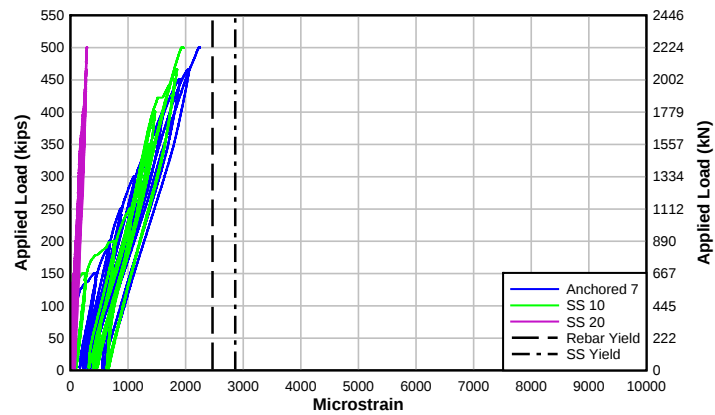


Figure A.74 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 7)

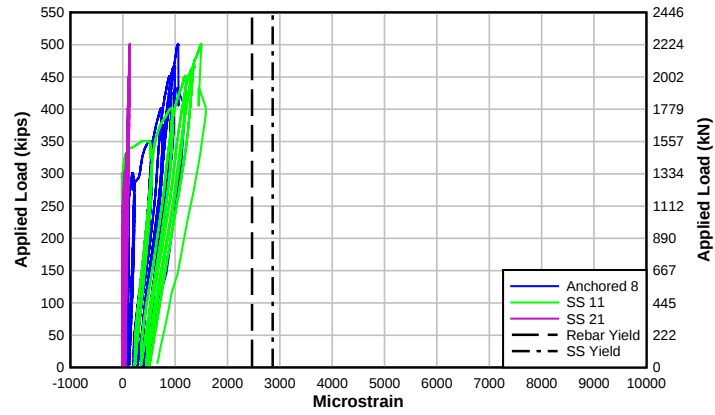


Figure A.75 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 8)

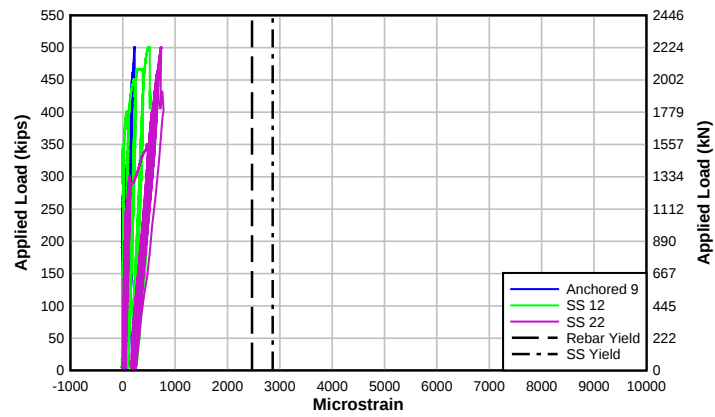


Figure A.76 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 9)

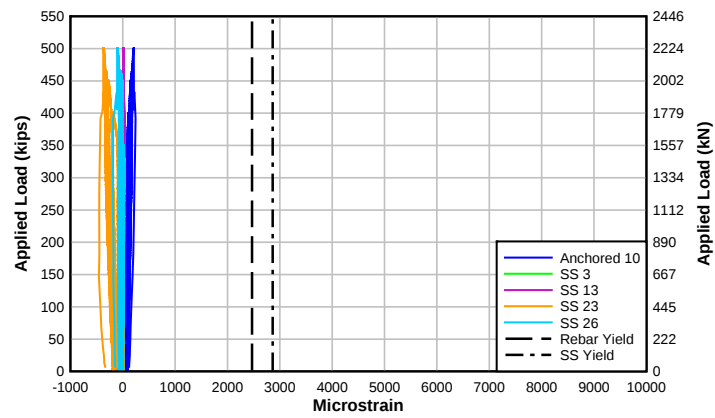


Figure A.77 – Specimen IT.45.Ld3(6).SS load-flexural bar strain (Section 10)

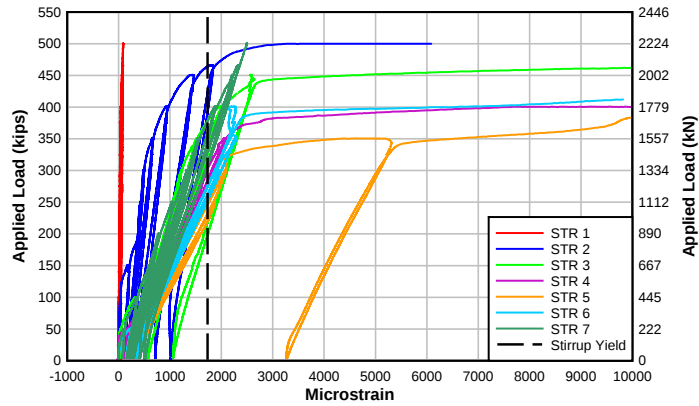


Figure A.78 – Specimen IT.45.Ld3(6).SS load-preformed crack stirrup strain

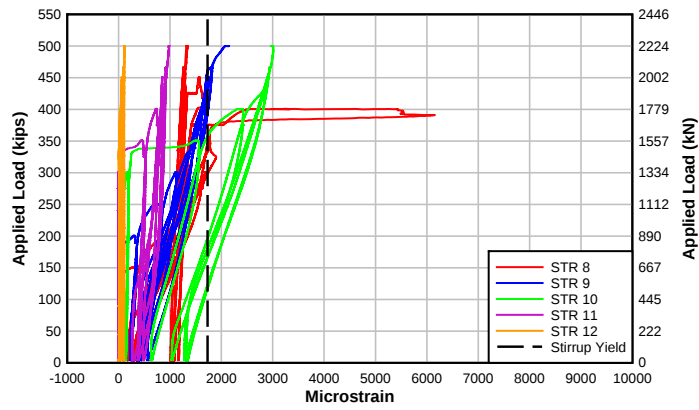


Figure A.79 – Specimen IT.45.Ld3(6).SS load-mid-height stirrup strain

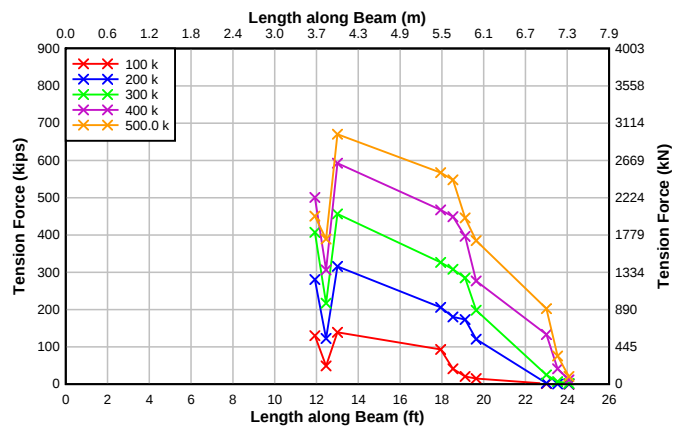


Figure A.80 – Specimen IT.45.Ld3(6).SS tension force in all flexural tension reinforcement along beam

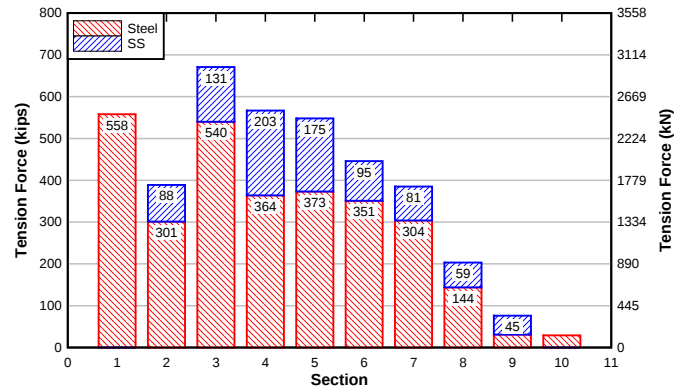


Figure A.81 – Specimen IT.45.Ld3(6).SS tension force contribution-section at failure



Figure A.82 – Specimen IT.0.0(6).Ti front and back failure photographs

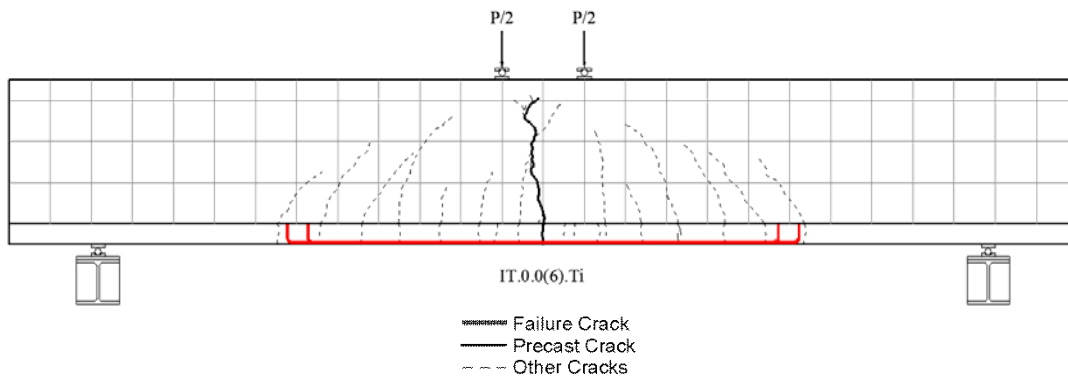


Figure A.83 – Specimen IT.0.0(6).Ti crack mapping with failure cracks

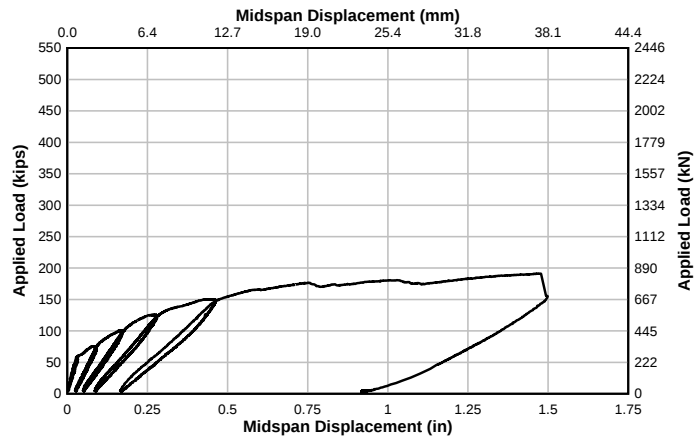


Figure A.84 – Specimen IT.0.0(6).Ti load-displacement

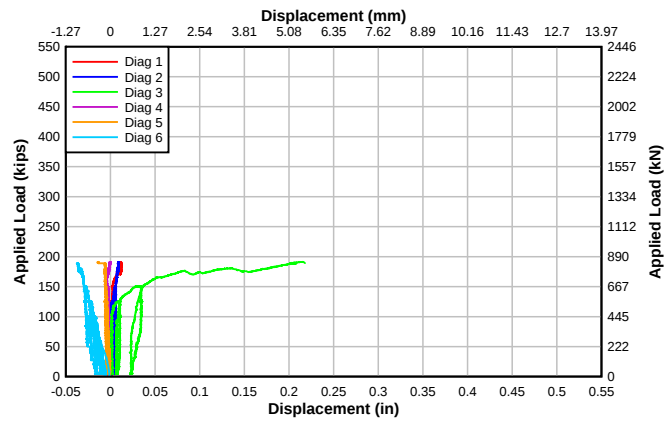


Figure A.85 – Specimen IT.0.0(6).Ti load-diagonal displacement

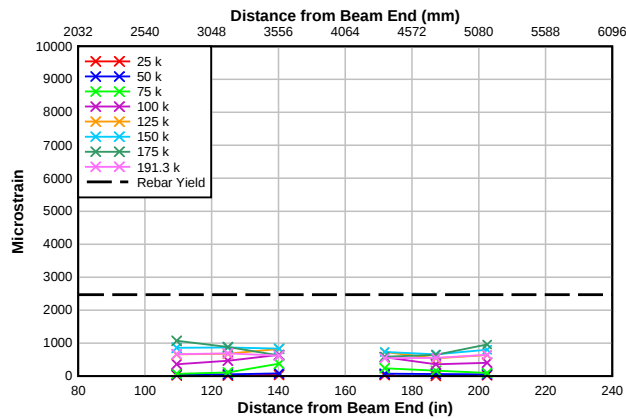


Figure A.86 – Specimen IT.0.0(6).Ti center cutoff reinforcing steel strain along specimen length

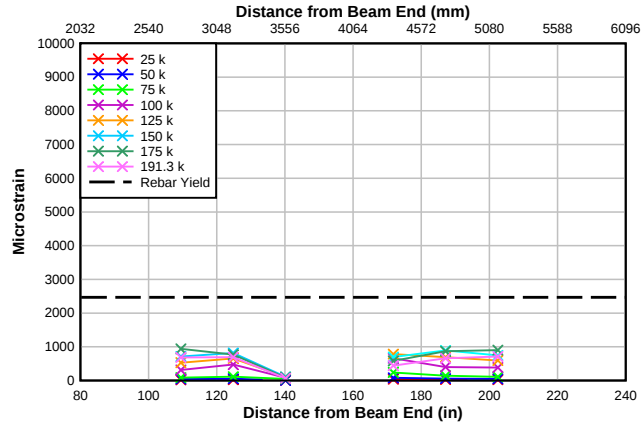


Figure A.87 – Specimen IT.0.0(6).Ti outside cutoff reinforcing steel strain along specimen length

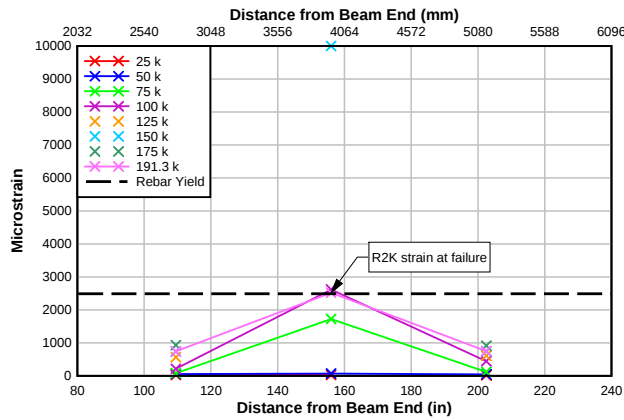


Figure A.88 – Specimen IT.0.0(6).Ti continuous #6 reinforcing steel strain along specimen length

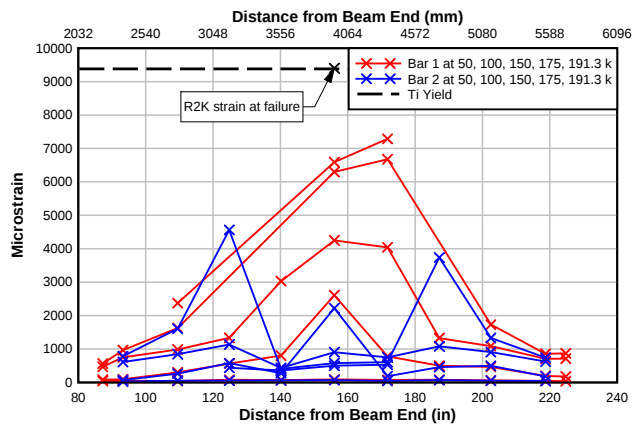


Figure A.89 – Specimen IT.0.0(6).Ti titanium bar strain along specimen length

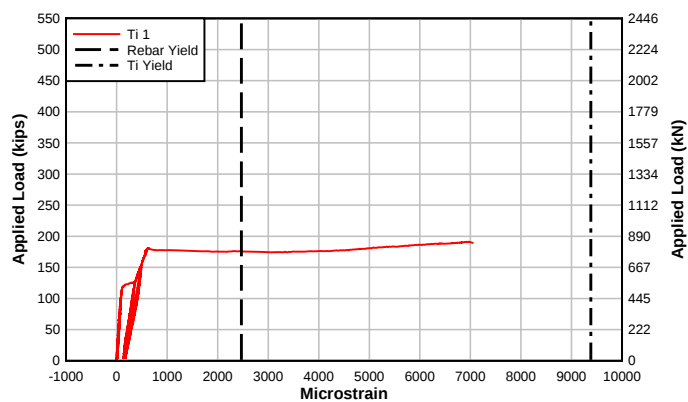


Figure A.90 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 1)

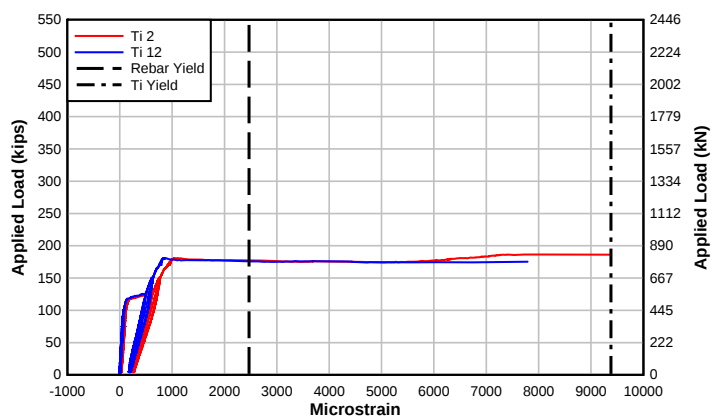


Figure A.91 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 2)

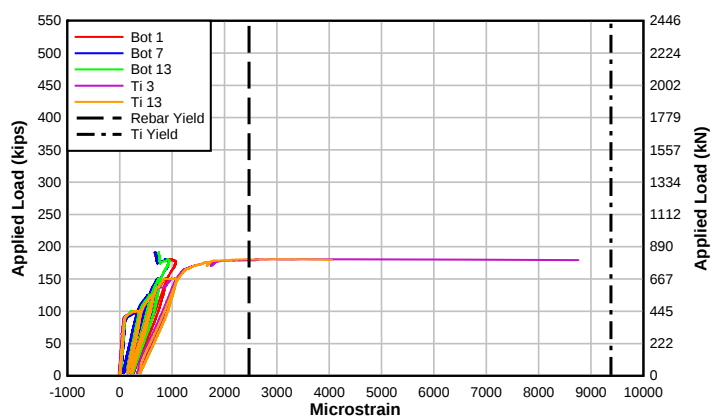


Figure A.92 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 3)

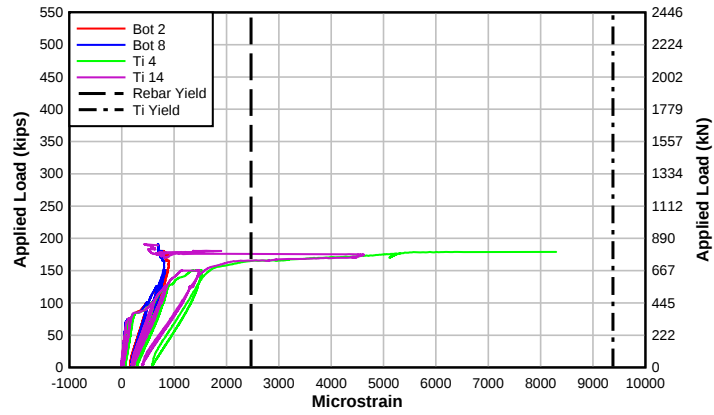


Figure A.93 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 4)

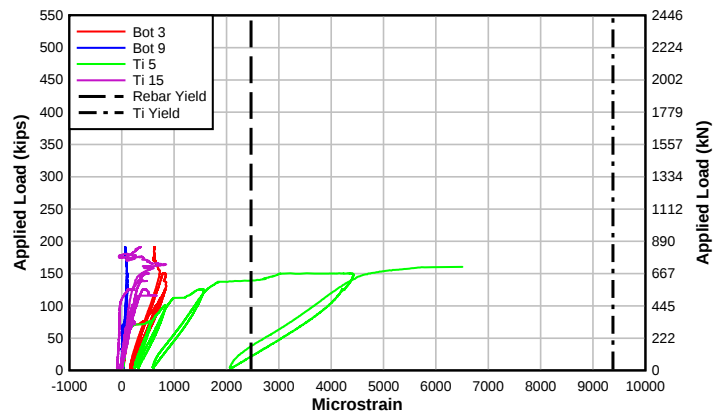


Figure A.94 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 5)

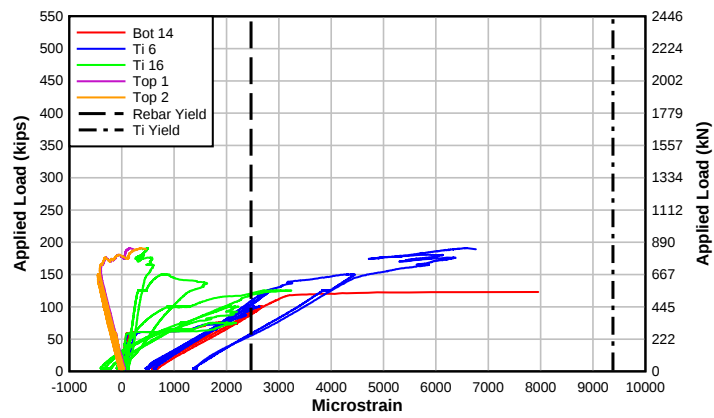


Figure A.95 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 6)

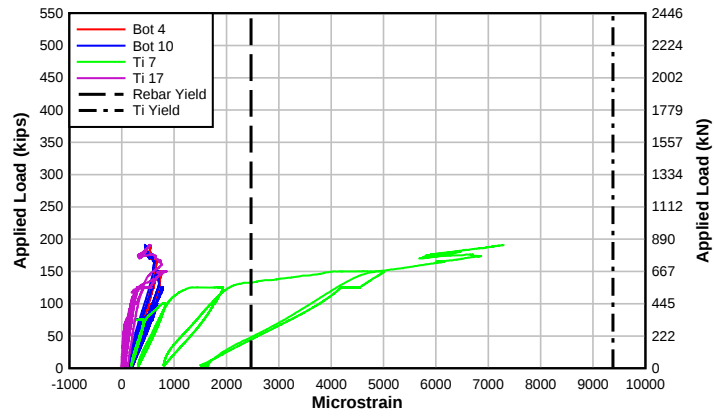


Figure A.96 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 7)

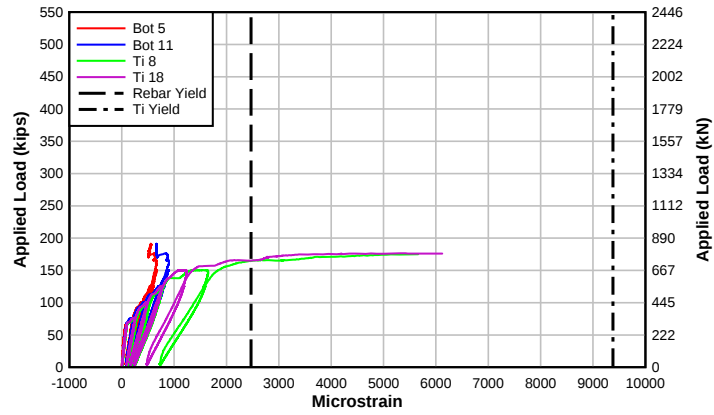


Figure A.97 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 8)

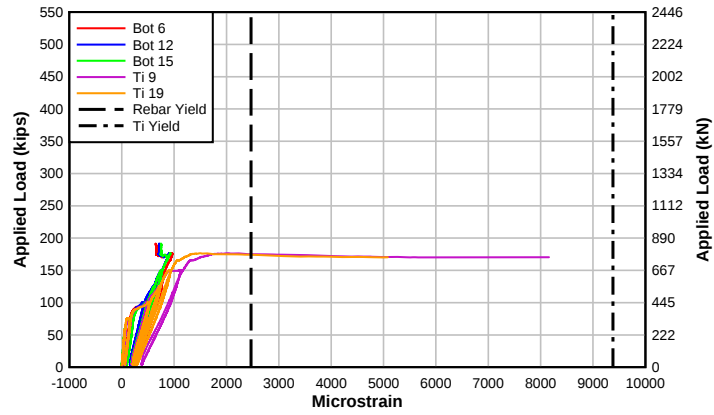


Figure A.98 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 9)

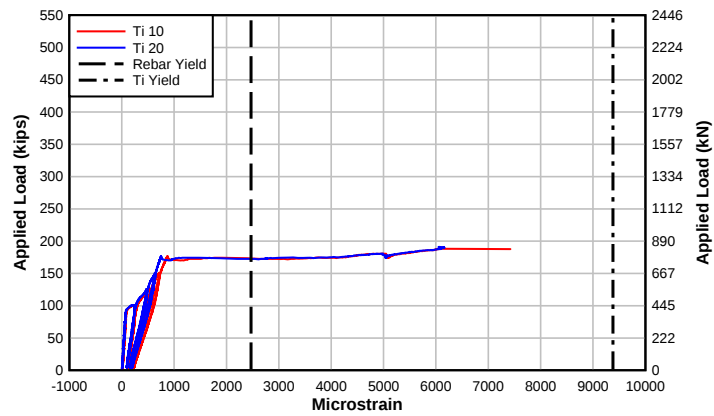


Figure A.99 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 10)

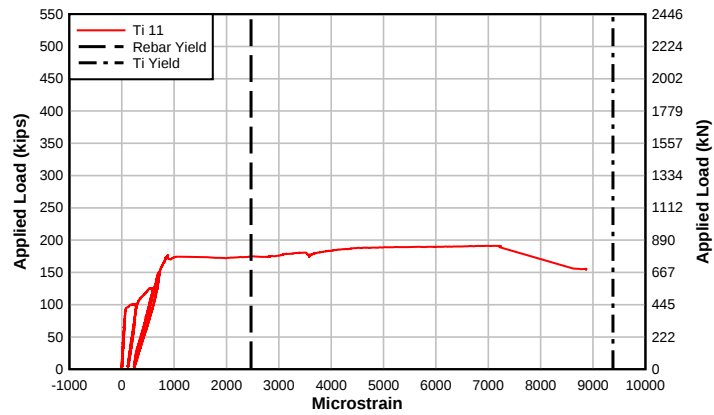


Figure A.100 – Specimen IT.0.0(6).Ti load-flexural bar strain (Section 10)

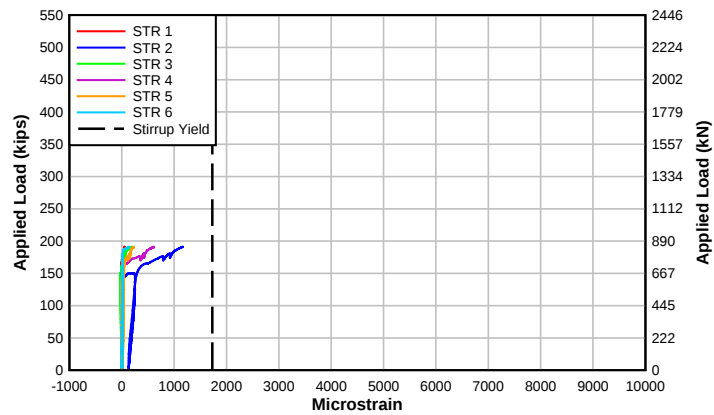


Figure A.101 – Specimen IT.0.0(6).Ti load-mid-height stirrup strain

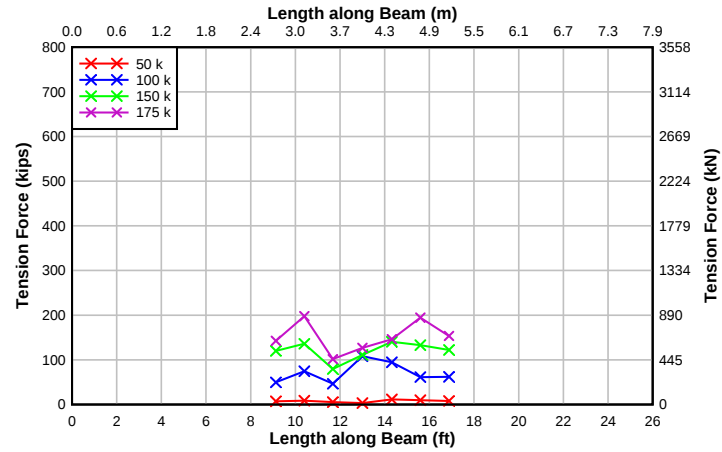


Figure A.102 – Specimen IT.0.0(6).Ti tension force in all flexural tension reinforcement along beam

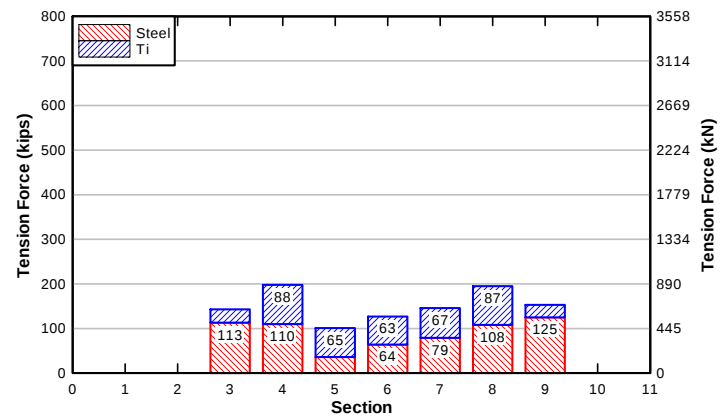


Figure A.103 – Specimen IT.0.0(6).Ti tension force contribution-section at 175 kips (780 kN)

Table A.1 – Summary of coupon data

Coupon		Yield Strength, f_y ksi (MPa)	Ultimate Strength, f_u ksi (MPa)	Elongation, e_u
Grade 40 #4 Rebar	1	50.3 (347)	79.4 (547)	0.327
	2	50.3 (347)	79.7 (549)	0.282
	3	50.1 (345)	79.7 (549)	0.313
	Average	50.2 (346)	79.6 (549)	0.307
Grade 60 #6 Rebar	1	72.3 (498)	106.7 (736)	0.250
	2	72.1 (497)	106.6 (735)	0.244
	3	72.1 (497)	106.6 (735)	0.296
	Average	72.2 (498)	106.6 (735)	0.263
Grade 60 #11 Rebar	1	70.1 (483)	105.9 (730)	0.229
	2	72.3 (498)	107.5 (741)	0.233
	3	72.4 (499)	107.5 (741)	0.231
	Average	71.6 (494)	107.0 (738)	0.231
Grade 75 #5 Stainless Steel	1	82.5 (569)	127.7 (880)	0.513
	2	83.8 (578)	127.0 (876)	0.442
	3	82.8 (571)	127.3 (878)	0.525
	Average	83.0 (572)	127.3 (878)	0.494
#5 Titanium	1	146.2 (1008)	159.0 (1096)	0.106
	2	143.6 (1009)	156.5 (1079)	0.130
	3	146.4 (1009)	158.8 (1095)	0.098
	Average	145.4 (1009)	158.1 (1090)	0.111