MaineDOT

Transportation Research Division

Technical Report 16-14

Advanced Bridge Safety Initiative: Phase 2

Task 1

Rivet Testing of Rivets Taken from Maine Truss Bridge

March 2016

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16. Abstract (Limit 200 words)

The Maine Department of Transportation (MaineDOT) has removed 25 rivets from an existing, older truss bridge. Many such truss bridges have low rating factors as determined using Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) guidelines due to the assumption of conservatively low rivet strength properties in the absence of known properties. To provide the MaineDOT with better information regarding rivet properties, The University of Maine (UMaine) has tested the rivets in tension to determine their strength properties. Work conducted under this task included assessing the best test method based on existing literature, fabricating test fixtures, machining test specimens from each rivet, conducting the strength tests, determining rivet strength properties from the test data, and reporting the test results to the MaineDOT in this report.

Rivet testing was conducted according to ASTM F606 Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets [and ASTM E8 Standard Test Methods for Tension Testing of Metallic Materials with variations as noted in this report. Rivets were machined to produce tension specimen with threaded grips at each end and a turned-down shank with dimensions adjusted from the standards to match provided rivet specimen. Rivets were tested in tension and mean yield strength (0.2% offset) was found to be 43.7 ksi and mean ultimate strength was found to be 69.6 ksi.

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Rivet Testing of Rivets Taken from Maine Truss Bridge

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Acronyms

AASHTO: American Association of State Highway and Transportation Officials
FHWA: Federal Highway Administration
MaineDOT: Maine Department of Transportation
UMaine: The University of Maine

Executive Summary

The Maine Department of Transportation (MaineDOT) has removed 25 rivets from an existing, older truss bridge. Many such truss bridges have low rating factors as determined using Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) guidelines due to the assumption of conservatively low rivet strength properties in the absence of known properties. To provide the MaineDOT with better information regarding rivet properties, The University of Maine (UMaine) has tested the rivets in tension to determine their strength properties. Work conducted under this task included assessing the best test method based on existing literature, fabricating test fixtures, machining test specimens from each rivet, conducting the strength tests, determining rivet strength properties from the test data, and reporting the test results to the MaineDOT in this report.

Rivet testing was conducted according to ASTM F606 Standard Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets [1] and ASTM E8 Standard Test Methods for Tension Testing of Metallic Materials [2] with variations as noted in this report. Rivets were machined to produce tension specimen with threaded grips at each end and a turned-down shank with dimensions adjusted from the standards to match provided rivet specimen. Rivets were tested in tension and mean yield strength (0.2% offset) was found to be 43.7 ksi and mean ultimate strength was found to be 69.6 ksi. A summary of results is presented in Table 1. Note that these values are for as-procured and tested specimen, and there may be unknown effects due to the flame cutting and extraction that could cause variations compared to in-situ rivets.

Table 1: Rivet strengths

Strength (23 Samples)	Mean (ksi)	Std. Dev. (ksi)	COV %
F_y Yield (0.2% Offset)	43.7	9.91	22.7
F_u Ultimate	69.6	4.60	6.60

For comparison, the Manual for Bridge Evaluation 2011 Second Edition AASHTO [3] gives F_u for: "Unknown rivet type and origin" as 50 ksi, Carbon Steel ASTM A141 or ASTM A502 Grade I as 60 ksi, and ASTM A502 Grade II as 80 ksi.

1 Specimen Fabrication

Due to the size of the rivets extracted, the specimens were prepared according to Figure 1 in January 2016 by the Advanced Manufacturing Center at UMaine. A typical machined rivet is shown in Figure 2.
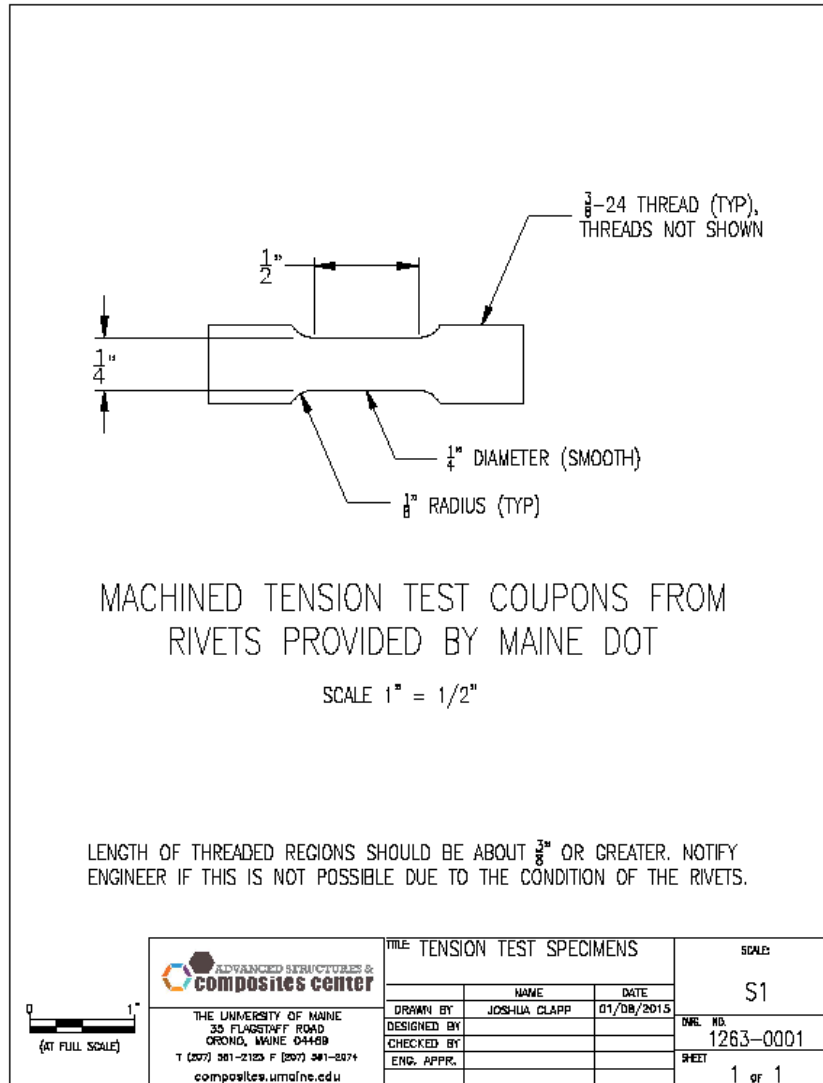

Figure 1: Machined rivet dimensional drawing

Figure 2: Typical machined rivet

Specimens were dimensioned at the UMaine Advanced Structures and Composites Center taking: diameter with three measurements at three locations along the gage length and averaging the value, and the average of three measurements of gage length. All measurement data are given in Appendix A.1, with metadata given in Table 3, measurements are given in Table 4, and calculated values are given in Table 5.

2   Testing

Testing was conducted in February 2016 at the UMaine Advanced Structures and Composites Center Mechanical Testing Laboratory using an Instron servo-hydraulic actuator (MTL #2 AS107) with a 5 kip load cell (AS601). The typical test setup is shown in Figure 3, with two internally threaded plates screwed onto the specimen, being held with hydraulic grips at 1,900 psi. Testing was first conducted in load control for specimen #01 to #05 inclusive, with approximate engineering strain rates through yield of approximately 0.01 in/in/min and at ultimate near 0.05 to 0.06 in/in/min. ASTM E8 [2] recommends a yield strain rate of 0.015 in/in/min per 7.6.3.2 and an ultimate strain rate of 0.05 in/in/min per 7.6.4. For the rest of the specimens displacement control was used to more precisely load the specimen. The specimen 20 strain rate was an outlier with a higher strain rate due to improperly entered data in the Ramp Generator Instron control system, but since the ultimate and yield strengths derived from the test were not outliers the data from that specimen is included. All of the specimen strain rate plots are shown in Appendix A.5.

Figure 3: Typical rivet testing setup

A typical specimen failure is shown in Figure 4, with well-defined necking and failure in the gage portion.

Figure 4: Typical rivet specimen after failure

3 Data Analysis

Data was recorded from the DAX software at a rate of 0.01 kHz. All load vs. position data is given in Section A.2. A typical load vs. position plot is provided in Figure 5 showing position of the crosshead (in) on the horizontal axis and the load (lbf) on the vertical axis.
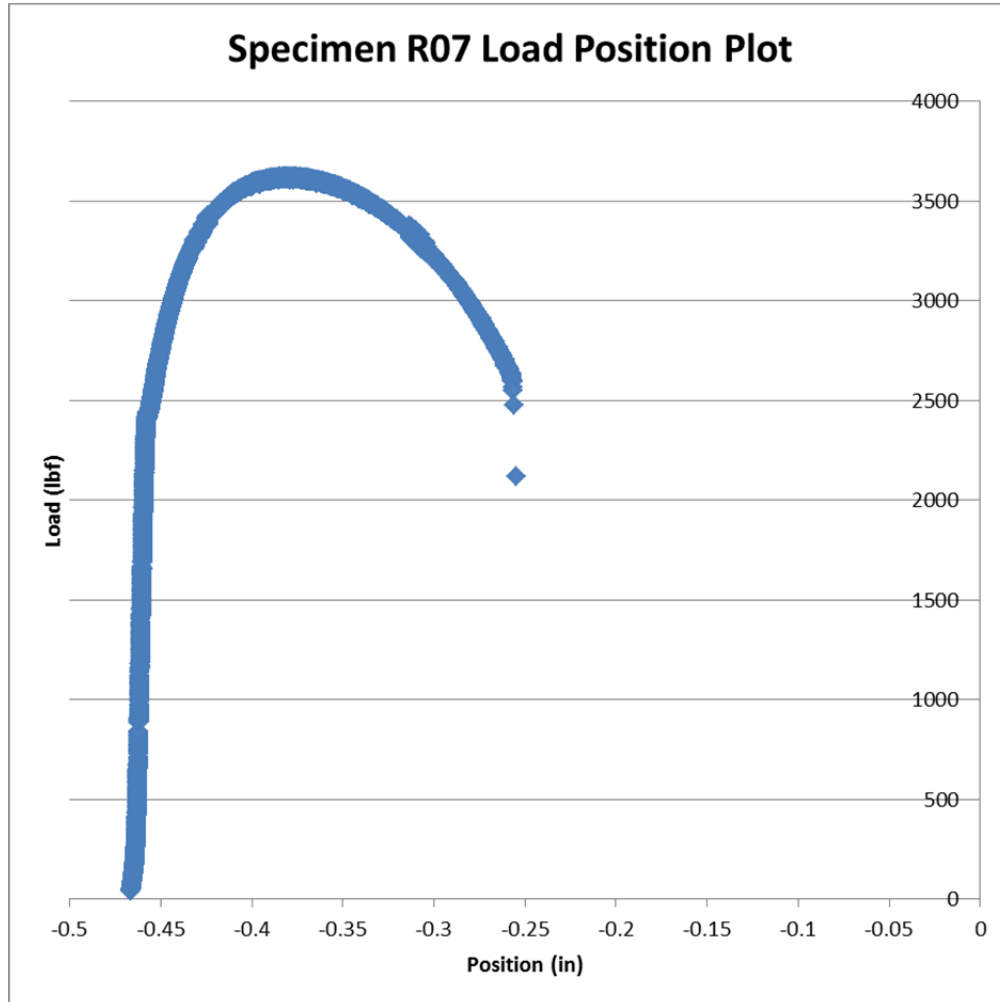

Figure 5: Typical load vs. position plot

Engineering stress (ksi) was calculated as the load divided by the original cross sectional area. Approximate engineering strain (in/in) is calculated as the change in displacement of the Instron cross-head from initial location divided by the gage length. Plots of the horizontal axis approximate engineering strain (in/in) vs. vertical axis engineering stress (ksi) are provided in Appendix A.3, and a typical stress vs. strain plot is shown in Figure 6.
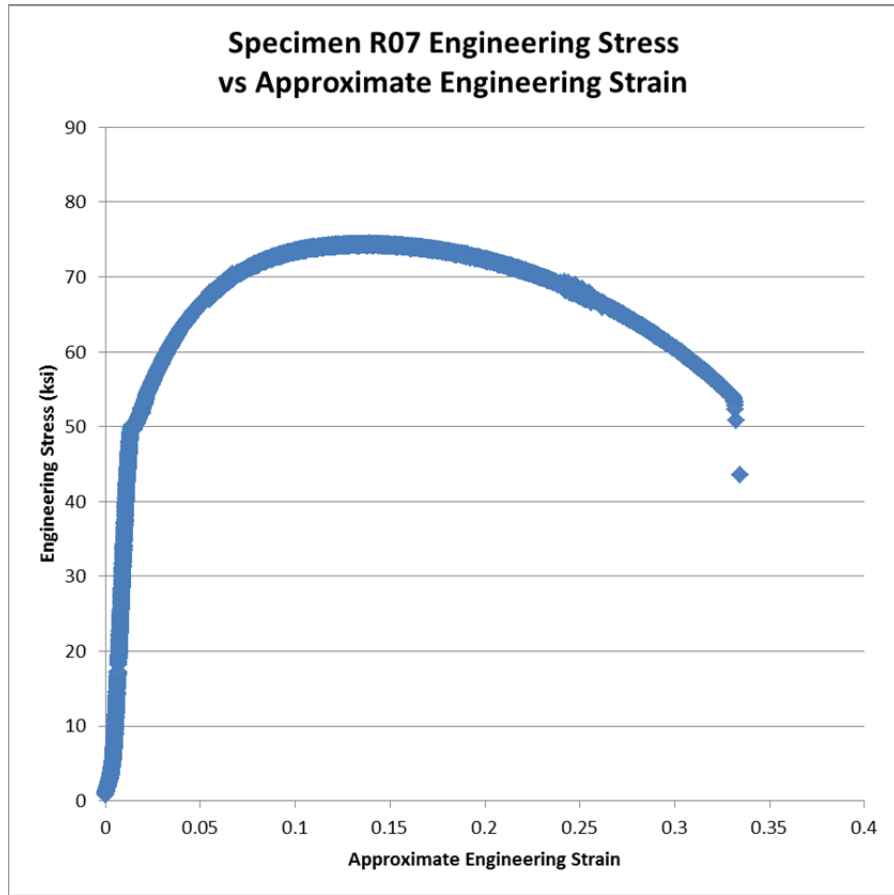
Figure 6: Typical engineering stress vs. approximate engineering strain

Yield strength was calculated using the 0.2% offset method. The vertical axis load (lbf) vs horizontal axis displacement (in) curve was plotted, in blue, and the linear portion of the curve, points considered in red, was fit with a best fit least squares regression linear fit in excel, shown as a green line. The best fit curve was then offset by 0.2% strain, shown as a red line, and the intersection with the load vs. displacement curve 5 point moving average was found, shown as a black asterisk. The equation and R^2 value for the curve fit of the linear portion of the load vs. displacement is shown on each plot. All yield plots are shown in Appendix A.4, and a typical yield plot is shown in Figure 7.
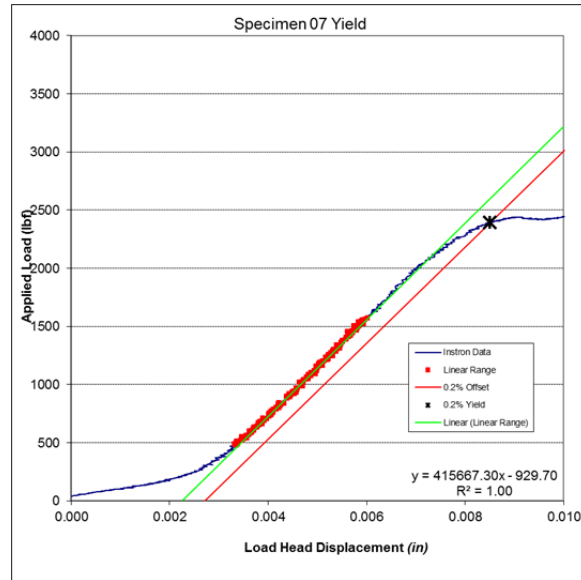
Figure 7: Typical yield curve

Strain rate was calculated for each specimen to verify compliance with standard strain rate at yield and failure requirements as described above. A typical horizontal axis engineering stress (ksi) vs. vertical axis strain rate (in/in/min) plot is shown in Figure 8, and all strain rate plots are provided in Appendix A.5.
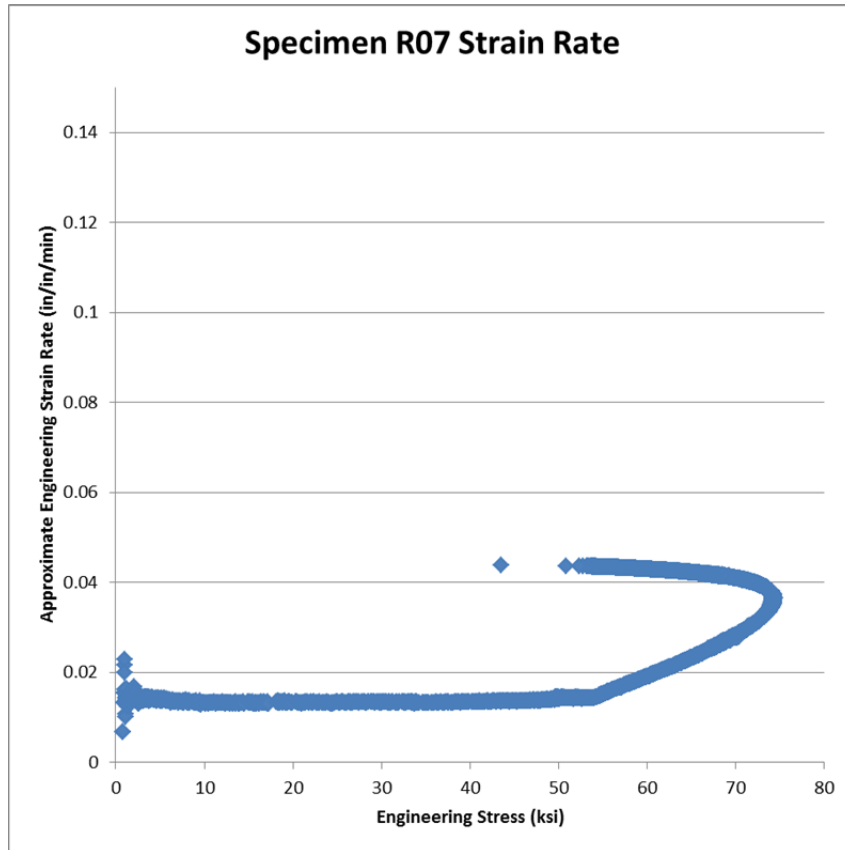
Figure 8: Typical strain rate plot

4 Detailed Test Results

Detailed results for each specimen are summarized in Table 4.

Table 2: Specimen test results

Specimen		F_y Yield Engineering Stress (ksi)	Ultimate Load (lbf)	F_u Ultimate Engineering Stress (ksi)
Type	Number	(0.2% Offset)	DAX	DAX
R	01	46.4	3228	65.7
R	02	47.3	3607	72.9
R	03	47.0	3565	72.4
R	04	44.0	3457	70.6
R	05	52.4	3848	80.1
R	06	44.9	3253	69.0
R	07	49.1	3621	74.4
R	08	45.6	3317	69.9
R	09	44.0	3200	69.1
R	10	51.2	3429	71.9
R	11	44.5	3295	67.5
R	12	40.7	3062	63.5
R	13	43.9	3172	65.2
R	14	52.3	3242	70.0
R	15	37.3	3059	63.0
R	16	39.9	3097	63.4
R	17	45.2	3197	64.5
R	18	47.6	3550	74.4
R	19	47.3	3796	76.6
R	20	46.7	3002	63.9
R	21	0.4	3217	69.0
R	22	45.6	3658	75.8
R	23	42.7	3269	69.2
	Mean	**43.7**	**3354**	**69.6**
	Std. Dev.	**9.91**	**236**	**4.60**
	COV	**22.7%**	**7.03%**	**6.60%**

Appendices

A.1   Specimen Dimensions

Table 3: Specimen measurement information

Specimen		Measurement Data			
Type	Number	Micrometer	Measurer	Date	Location
R	01	AS 685	Scott Tomlinson	2/2/2016 8:36	ASCC 248
R	02	AS 685	Scott Tomlinson	2/3/2016 12:00	ASCC 248
R	03	AS 685	Scott Tomlinson	2/3/2016 12:00	ASCC 248
R	04	AS 685	Scott Tomlinson	2/3/2016 12:00	ASCC 248
R	05	AS 685	Ryan Flanagan	2/5/2016 10:15	ASCC 252
R	06	AS 685	Ryan Flanagan	2/5/2016 10:15	ASCC 252
R	07	AS 685	Ryan Flanagan	2/5/2016 10:30	ASCC 252
R	08	AS 685	Ryan Flanagan	2/5/2016 10:30	ASCC 252
R	09	AS 685	Ryan Flanagan	2/5/2016 10:30	ASCC 252
R	10	AS 685	Ryan Flanagan	2/5/2016 10:30	ASCC 252
R	11	AS 685	Ryan Flanagan	2/5/2016 10:50	ASCC 252
R	12	AS 685	Ryan Flanagan	2/6/2016 10:50	ASCC 252
R	13	AS 685	Ryan Flanagan	2/5/2016 11:00	ASCC 252
R	14	AS 685	Ryan Flanagan	2/5/2016 11:05	ASCC 252
R	15	AS 685	Ryan Flanagan	2/5/2016 11:10	ASCC 252
R	16	AS 685	Ryan Flanagan	2/5/2016 11:15	ASCC 252
R	17	AS 685	Ryan Flanagan	2/5/2016 11:17	ASCC 252
R	18	AS 685	Ryan Flanagan	2/5/2016 11:20	ASCC 252
R	19	AS 685	Ryan Flanagan	2/5/2016 11:22	ASCC 252
R	20	AS 685	Ryan Flanagan	2/5/2016 11:25	ASCC 252
R	21	AS 685	Ryan Flanagan	2/5/2016 11:27	ASCC 252
R	22	AS 685	Ryan Flanagan	2/5/2016 11:30	ASCC 252
R	23	AS 685	Ryan Flanagan	2/5/2016 11:33	ASCC 252

Table 4: Specimen measurements

Specimen		Measurements in Inches											
		Top Diameter			Middle Diameter			Bottom Diameter			Gage Length		
Type	#	1	2	3	1	2	3	1	2	3	1	2	3
R	01	0.2495	0.2500	0.2490	0.2505	0.2500	0.2495	0.2510	0.2515	0.2505	0.5595	0.5790	0.5745
R	02	0.2525	0.2510	0.2510	0.2505	0.2490	0.2490	0.2540	0.2500	0.2525	0.5650	0.5525	0.5460
R	03	0.2510	0.2510	0.2510	0.2505	0.2500	0.2500	0.2510	0.2500	0.2485	0.5295	0.5325	0.5230
R	04	0.2500	0.2500	0.2495	0.2485	0.2485	0.2490	0.2510	0.2505	0.2500	0.5030	0.4995	0.5055
R	05	0.2470	0.2475	0.2475	0.2460	0.2470	0.2455	0.2480	0.2490	0.2490	0.6425	0.6670	0.6505
R	06	0.2465	0.2465	0.2470	0.2440	0.2440	0.2435	0.2455	0.2445	0.2440	0.6240	0.6285	0.6170
R	07	0.2520	0.2500	0.2500	0.2470	0.2485	0.2490	0.2475	0.2480	0.2480	0.6390	0.6350	0.6215
R	08	0.2445	0.2485	0.2455	0.2445	0.2450	0.2450	0.2460	0.2475	0.2460	0.6395	0.6360	0.6390
R	09	0.2450	0.2455	0.2445	0.2440	0.2415	0.2400	0.2405	0.2430	0.2420	0.5685	0.5700	0.5740
R	10	0.2475	0.2470	0.2465	0.2430	0.2465	0.2475	0.2465	0.2470	0.2465	0.6475	0.6685	0.6570
R	11	0.2510	0.2495	0.2495	0.2470	0.2490	0.2475	0.2500	0.2505	0.2495	0.6455	0.6440	0.6500
R	12	0.2480	0.2475	0.2480	0.2475	0.2480	0.2455	0.2485	0.2490	0.2480	0.5795	0.5830	0.5830
R	13	0.2490	0.2490	0.2490	0.2490	0.2480	0.2480	0.2495	0.2490	0.2490	0.6045	0.5995	0.6060
R	14	0.2390	0.2395	0.2380	0.2435	0.2435	0.2425	0.2465	0.2465	0.2470	0.6325	0.6325	0.6345
R	15	0.2470	0.2485	0.2470	0.2485	0.2480	0.2480	0.2510	0.2490	0.2505	0.6340	0.6365	0.6405
R	16	0.2500	0.2495	0.2490	0.2495	0.2485	0.2490	0.2500	0.2500	0.2500	0.6935	0.6895	0.6800
R	17	0.2485	0.2500	0.2485	0.2510	0.2485	0.2505	0.2545	0.2540	0.2550	0.5900	0.5970	0.5955
R	18	0.2445	0.2475	0.2455	0.2470	0.2470	0.2445	0.2480	0.2475	0.2465	0.6330	0.6270	0.6260
R	19	0.2530	0.2550	0.2535	0.2510	0.2505	0.2510	0.2490	0.2485	0.2495	0.6055	0.6045	0.6050
R	20	0.2435	0.2470	0.2460	0.2445	0.2435	0.2445	0.2445	0.2435	0.2440	0.5855	0.5775	0.5770
R	21	0.2445	0.2465	0.2440	0.2425	0.2415	0.2440	0.2435	0.2435	0.2435	0.6345	0.6265	0.6340
R	22	0.2475	0.2480	0.2475	0.2465	0.2470	0.2470	0.2495	0.2500	0.2480	0.6110	0.6190	0.6255
R	23	0.2445	0.2445	0.2455	0.2445	0.2445	0.2455	0.2470	0.2460	0.2460	0.6390	0.6240	0.6170

Table 5: Calculated specimen dimensions

| Specimen		Area		Measurements (in)								COV (%)			
			Diameter	Mean				Std. Dev.							
Type	#	In^2		Top	Middle	Bottom	Gage	Top	Middle	Bottom	Gage	Top	Middle	Bottom	Gage
R	01	0.0492	0.2502	0.5341	0.2500	0.2510	0.5710	0.0004	0.0004	0.0004	0.0083	0.08	0.16	0.16	1.46
R	02	0.0495	0.2511	0.5569	0.2495	0.2522	0.5545	0.0007	0.0007	0.0016	0.0079	0.13	0.28	0.65	1.42
R	03	0.0492	0.2503	0.5519	0.2502	0.2498	0.5283	0.0000	0.0002	0.0010	0.0040	0.00	0.09	0.41	0.75
R	04	0.0490	0.2497	0.5459	0.2487	0.2505	0.5027	0.0002	0.0002	0.0004	0.0025	0.04	0.09	0.16	0.49
R	05	0.0481	0.2474	0.5752	0.2462	0.2487	0.6533	0.0002	0.0006	0.0005	0.0102	0.04	0.25	0.19	1.56
R	06	0.0472	0.2451	0.5698	0.2438	0.2447	0.6232	0.0002	0.0002	0.0006	0.0047	0.04	0.10	0.25	0.76
R	07	0.0487	0.2489	0.5734	0.2482	0.2478	0.6318	0.0009	0.0008	0.0002	0.0075	0.16	0.34	0.10	1.18
R	08	0.0475	0.2458	0.5741	0.2448	0.2465	0.6382	0.0017	0.0002	0.0007	0.0015	0.30	0.10	0.29	0.24
R	09	0.0463	0.2429	0.5598	0.2418	0.2418	0.5708	0.0004	0.0016	0.0010	0.0023	0.07	0.68	0.42	0.41
R	10	0.0477	0.2464	0.5778	0.2457	0.2467	0.6577	0.0004	0.0019	0.0002	0.0086	0.07	0.79	0.10	1.31
R	11	0.0488	0.2493	0.5769	0.2478	0.2500	0.6465	0.0007	0.0008	0.0004	0.0025	0.12	0.34	0.16	0.39
R	12	0.0482	0.2478	0.5625	0.2470	0.2485	0.5818	0.0002	0.0011	0.0004	0.0016	0.04	0.44	0.16	0.28
R	13	0.0486	0.2488	0.5686	0.2483	0.2492	0.6033	0.0000	0.0005	0.0002	0.0028	0.00	0.19	0.09	0.46
R	14	0.0463	0.2429	0.5703	0.2432	0.2467	0.6332	0.0006	0.0005	0.0002	0.0009	0.11	0.19	0.10	0.15
R	15	0.0485	0.2486	0.5743	0.2482	0.2502	0.6370	0.0007	0.0002	0.0008	0.0027	0.12	0.09	0.34	0.42
R	16	0.0489	0.2495	0.5750	0.2490	0.2500	0.6877	0.0004	0.0004	0.0000	0.0057	0.07	0.16	0.00	0.82
R	17	0.0495	0.2512	0.5674	0.2500	0.2545	0.5942	0.0007	0.0011	0.0004	0.0030	0.12	0.43	0.16	0.51
R	18	0.0477	0.2464	0.5707	0.2462	0.2473	0.6287	0.0012	0.0012	0.0006	0.0031	0.22	0.48	0.25	0.49
R	19	0.0496	0.2512	0.5688	0.2508	0.2490	0.6050	0.0008	0.0002	0.0004	0.0004	0.15	0.09	0.16	0.07
R	20	0.0470	0.2446	0.5580	0.2442	0.2440	0.5800	0.0015	0.0005	0.0004	0.0039	0.26	0.19	0.17	0.67
R	21	0.0467	0.2437	0.5688	0.2427	0.2435	0.6317	0.0011	0.0010	0.0000	0.0037	0.19	0.42	0.00	0.58
R	22	0.0483	0.2479	0.5700	0.2468	0.2492	0.6185	0.0002	0.0002	0.0008	0.0059	0.04	0.10	0.34	0.96
R	23	0.0473	0.2453	0.5704	0.2448	0.2463	0.6267	0.0005	0.0005	0.0005	0.0092	0.08	0.19	0.19	1.46

A.2   Load vs. Position Plots

The load is plotted against position data obtained for each machined rivet specimen is provided in this appendix.

Specimen R21 Load Position Plot

Specimen R22 Load Position Plot

Specimen R23 Load Position Plot
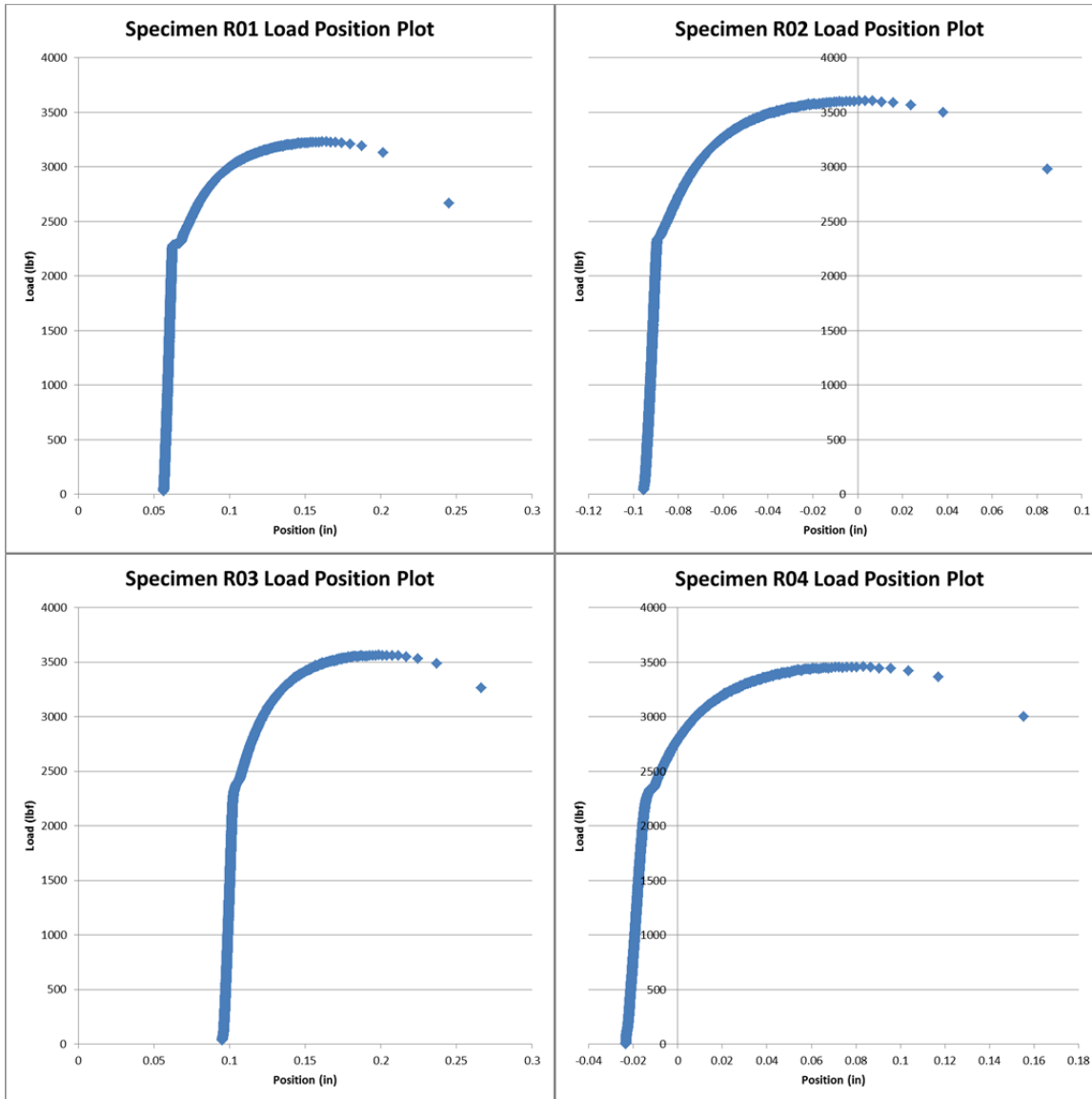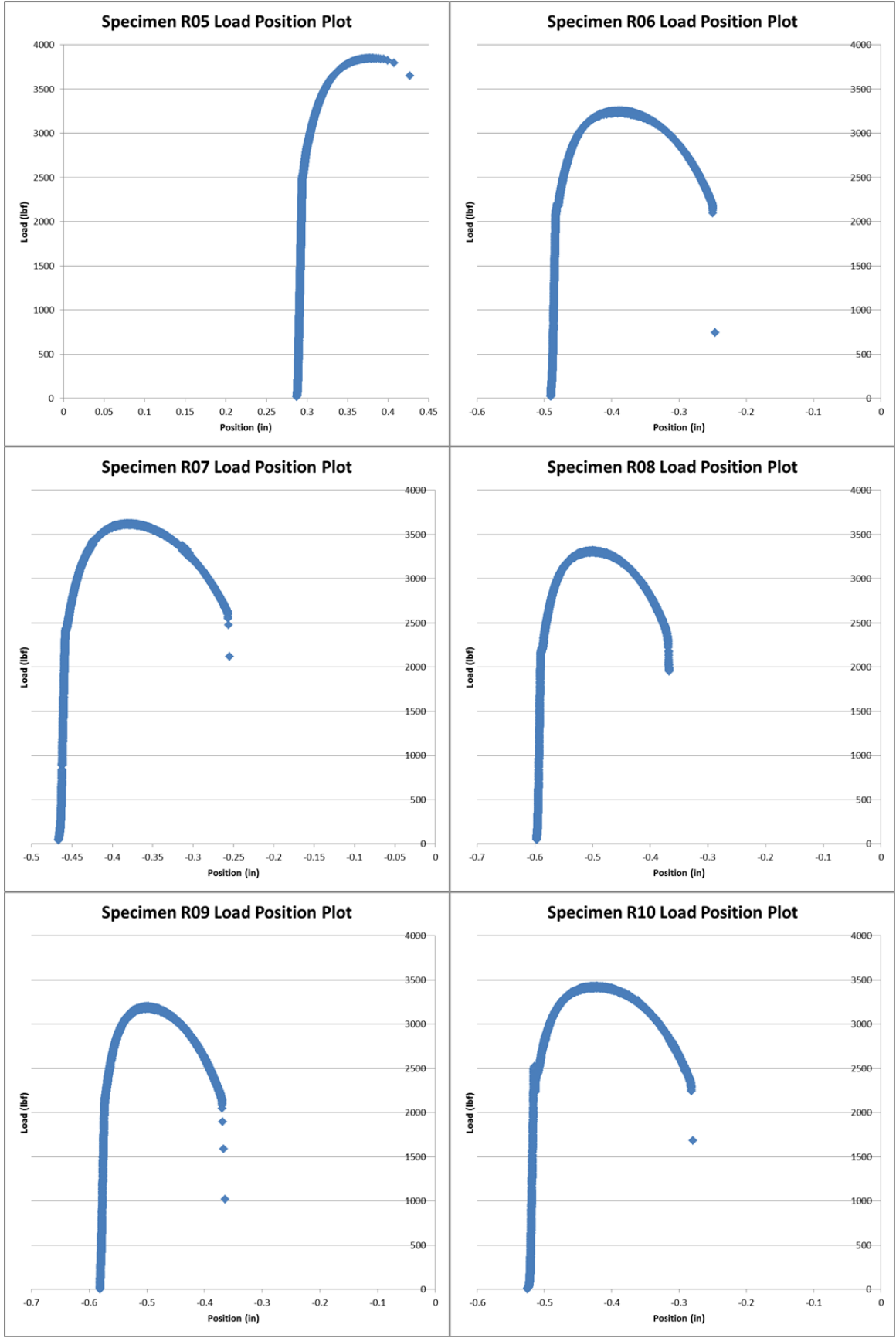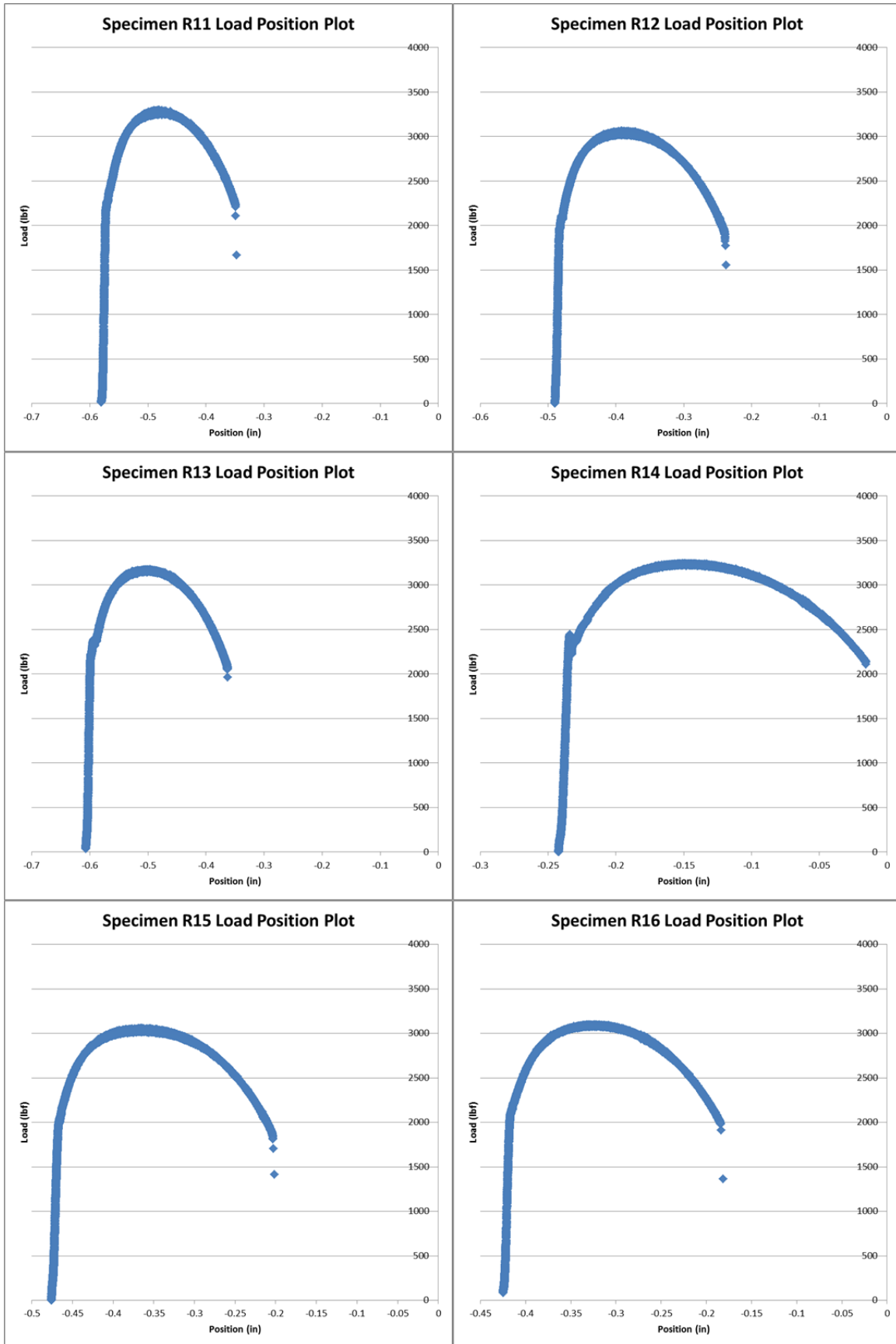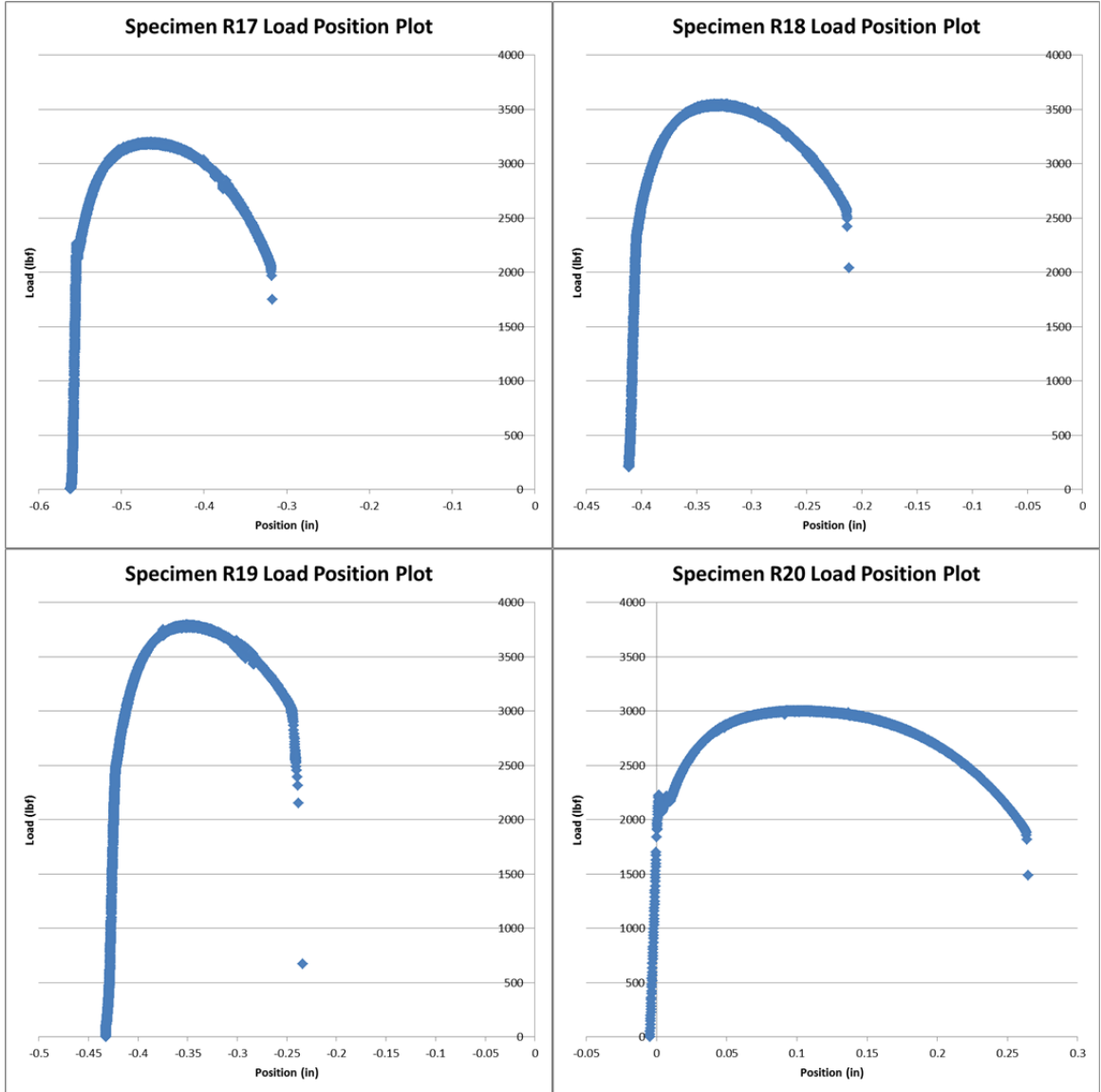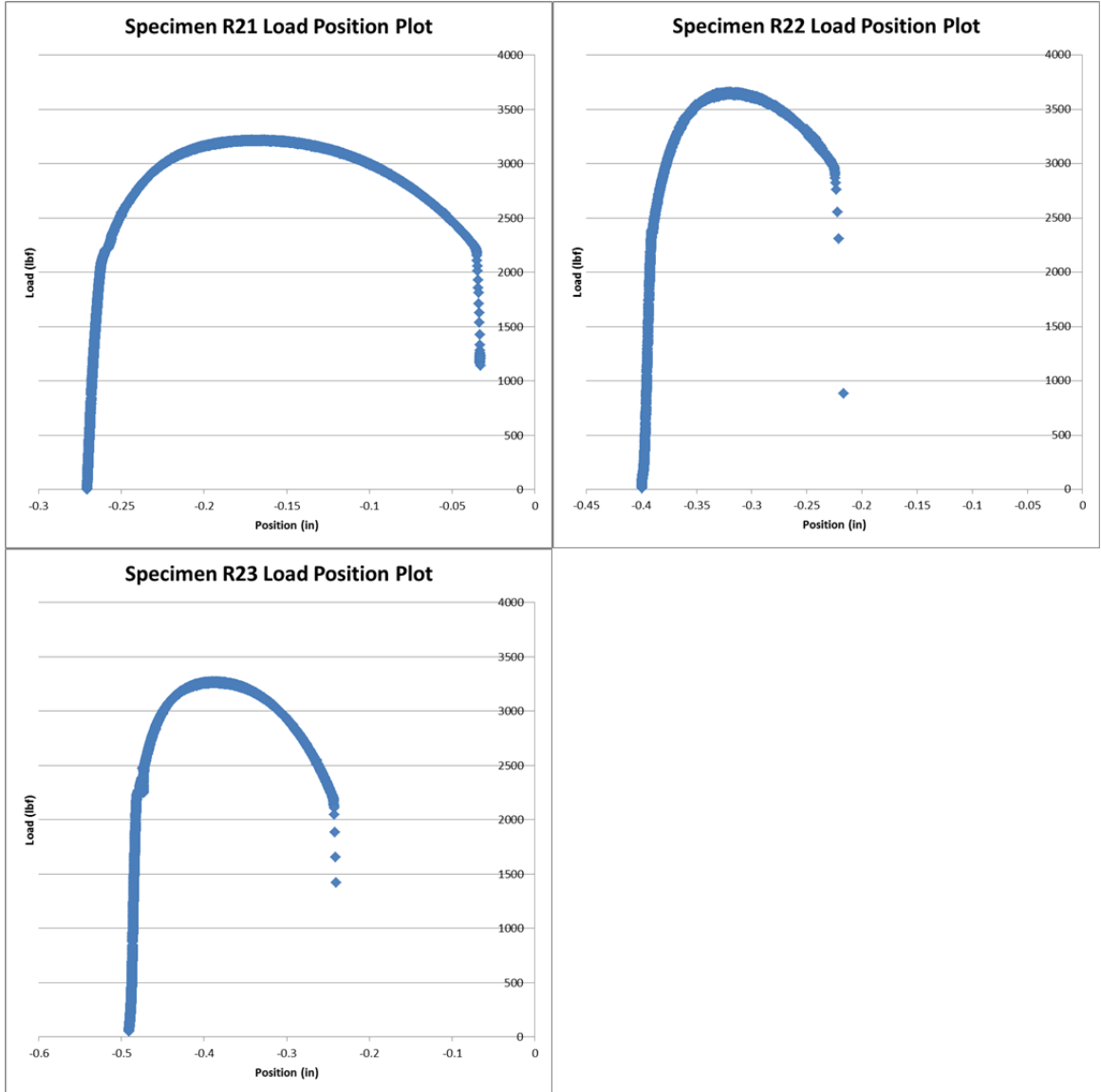
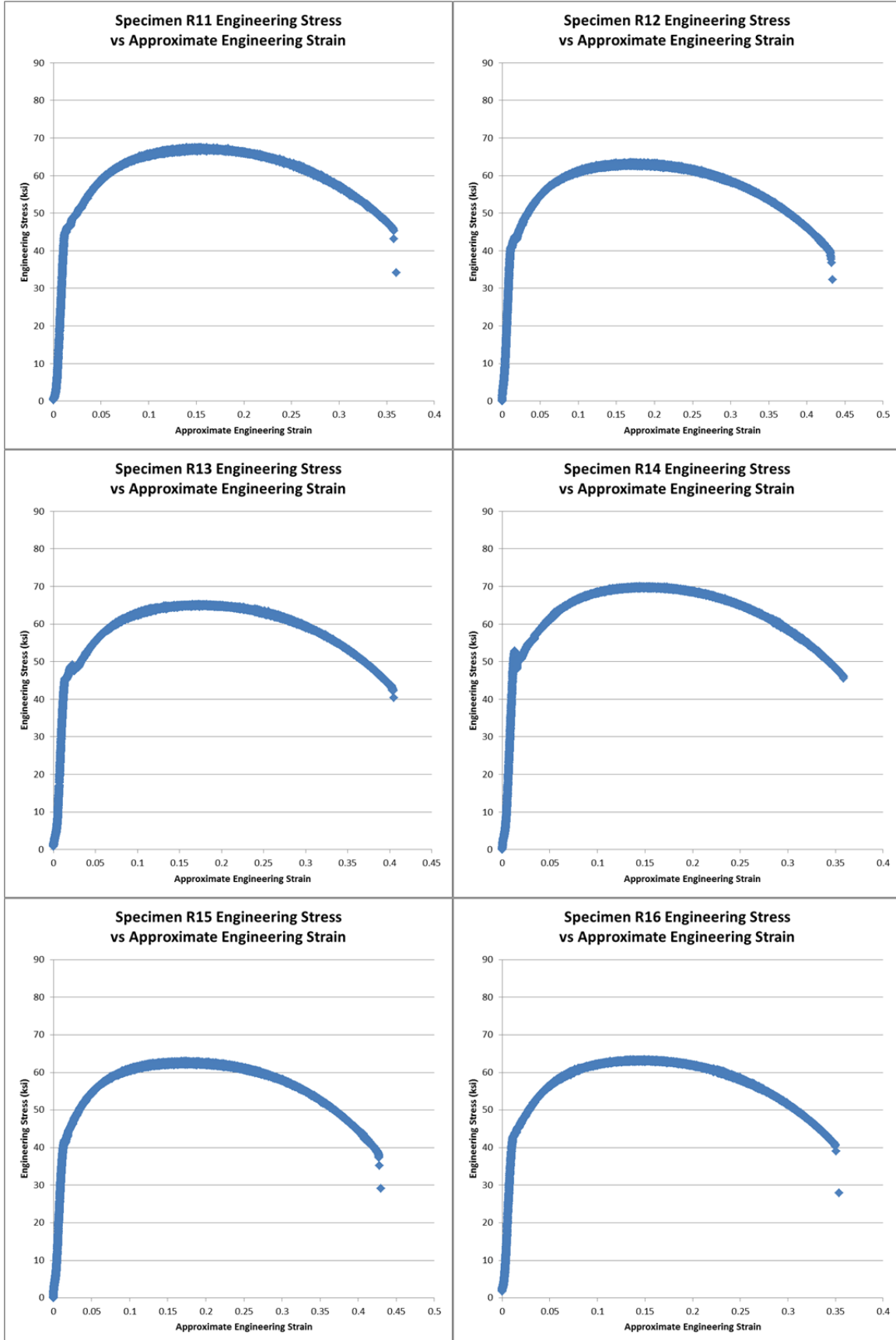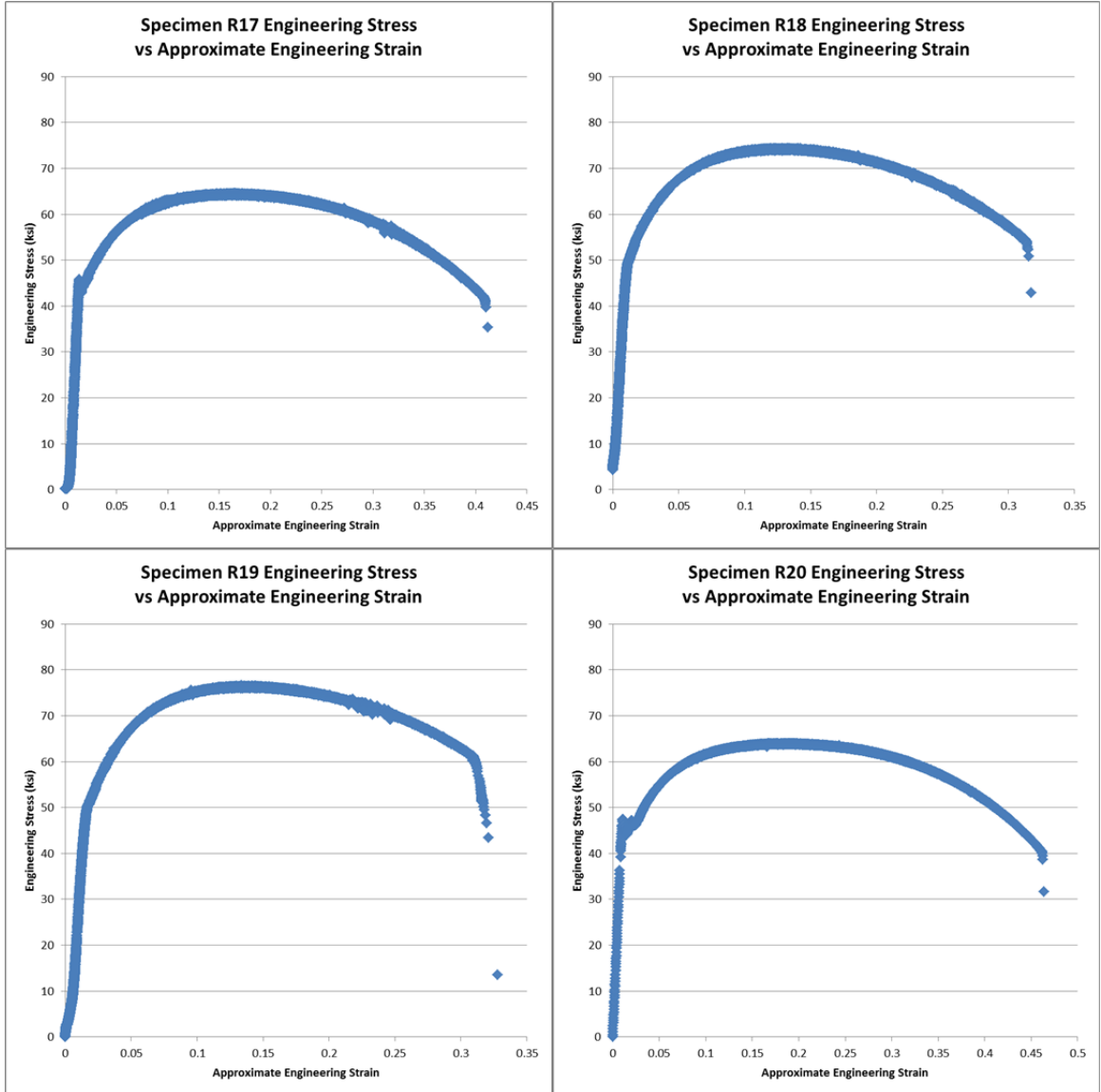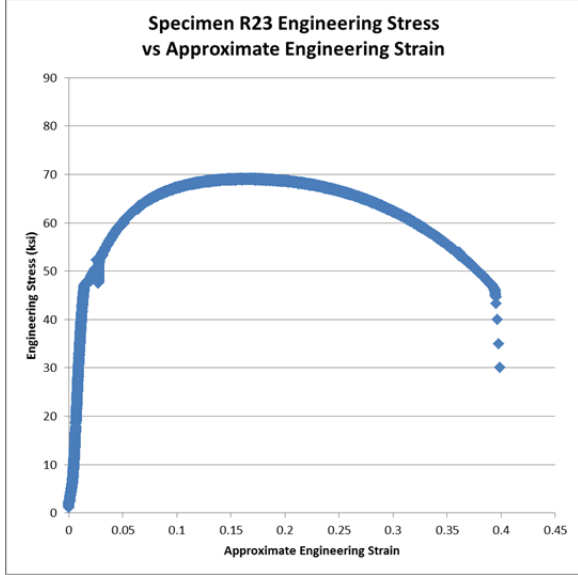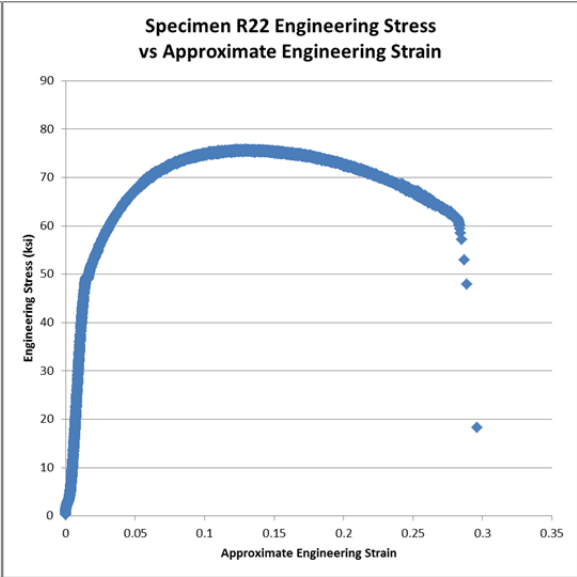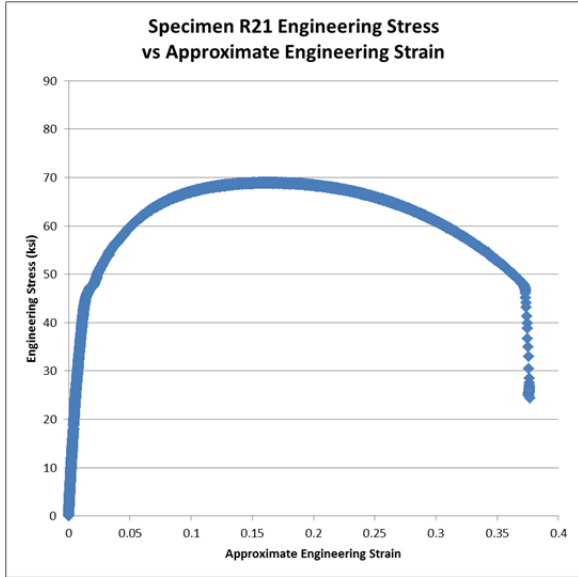## A.3 Engineering Stress vs. Approximate Engineering Strain

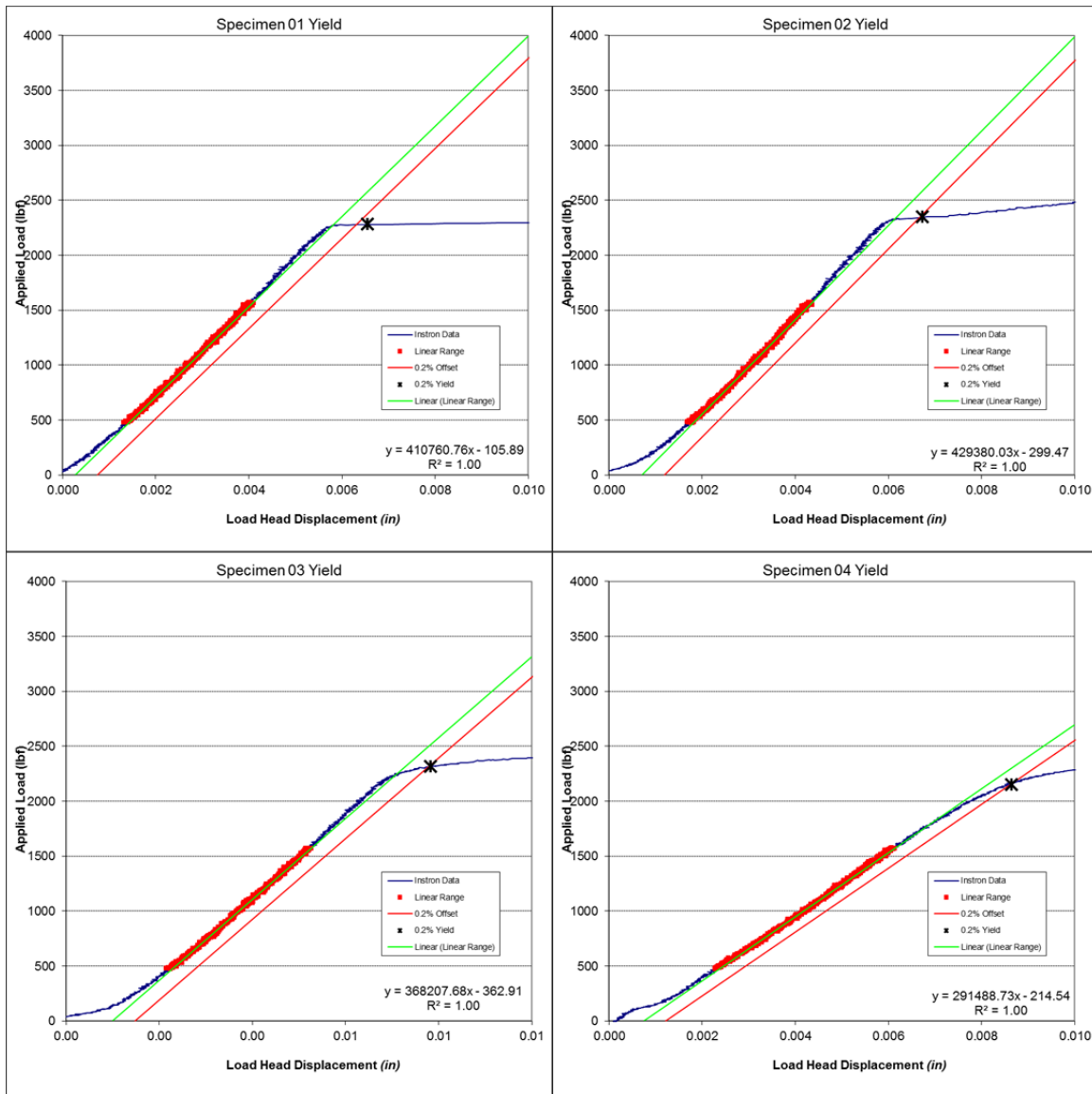The engineering stress is plotted against the approximate engineering strain for each rivet specimen in this appendix.
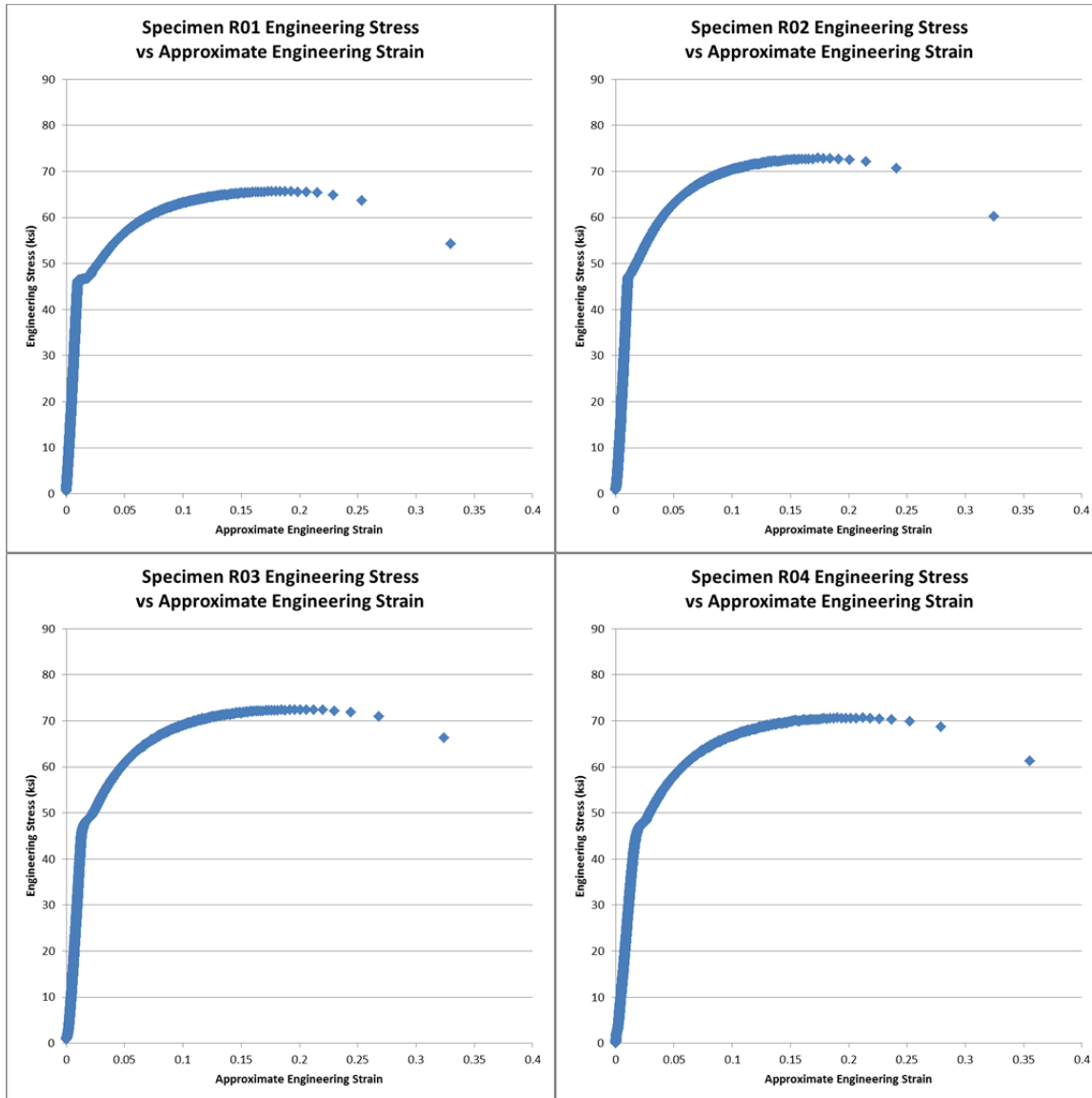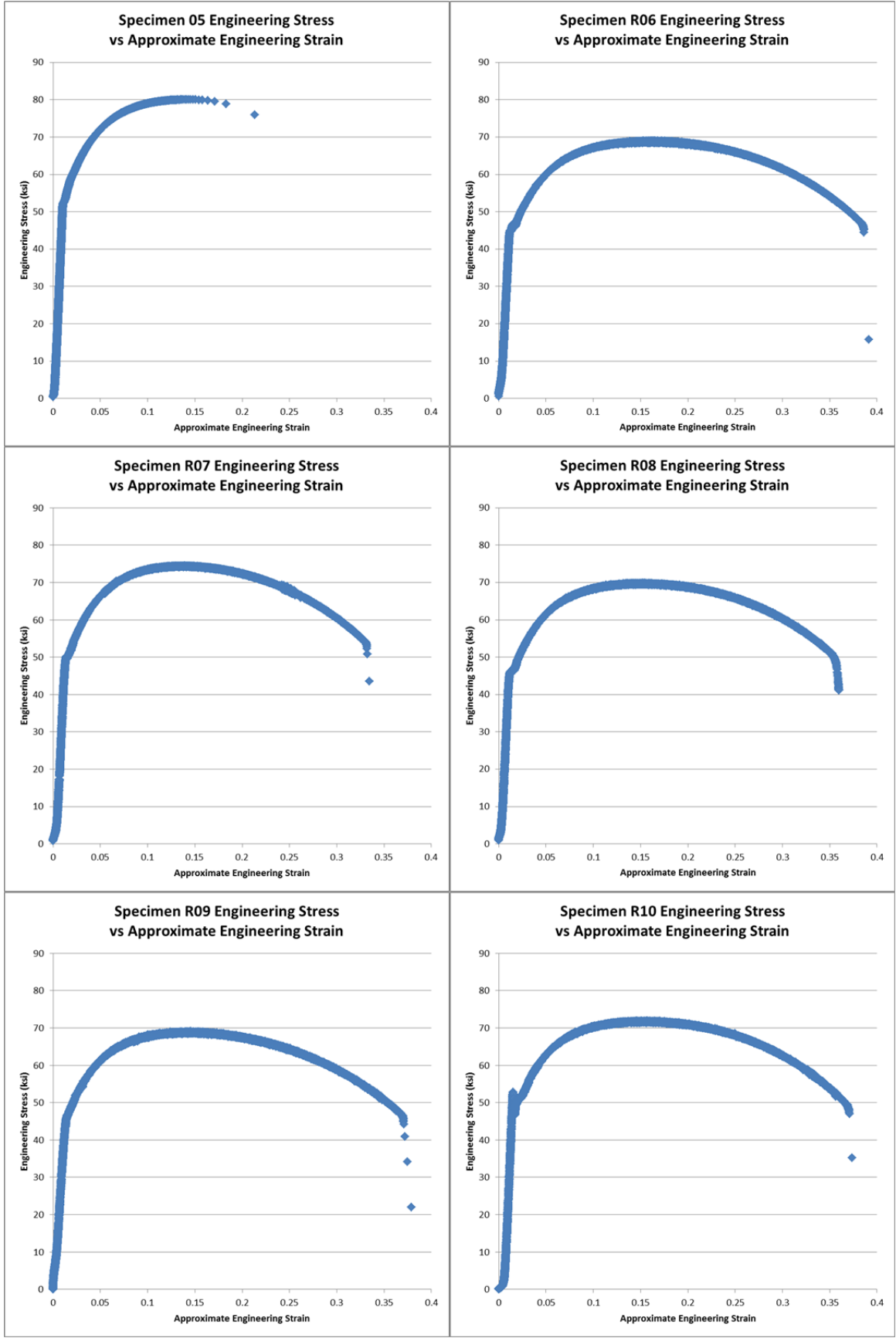
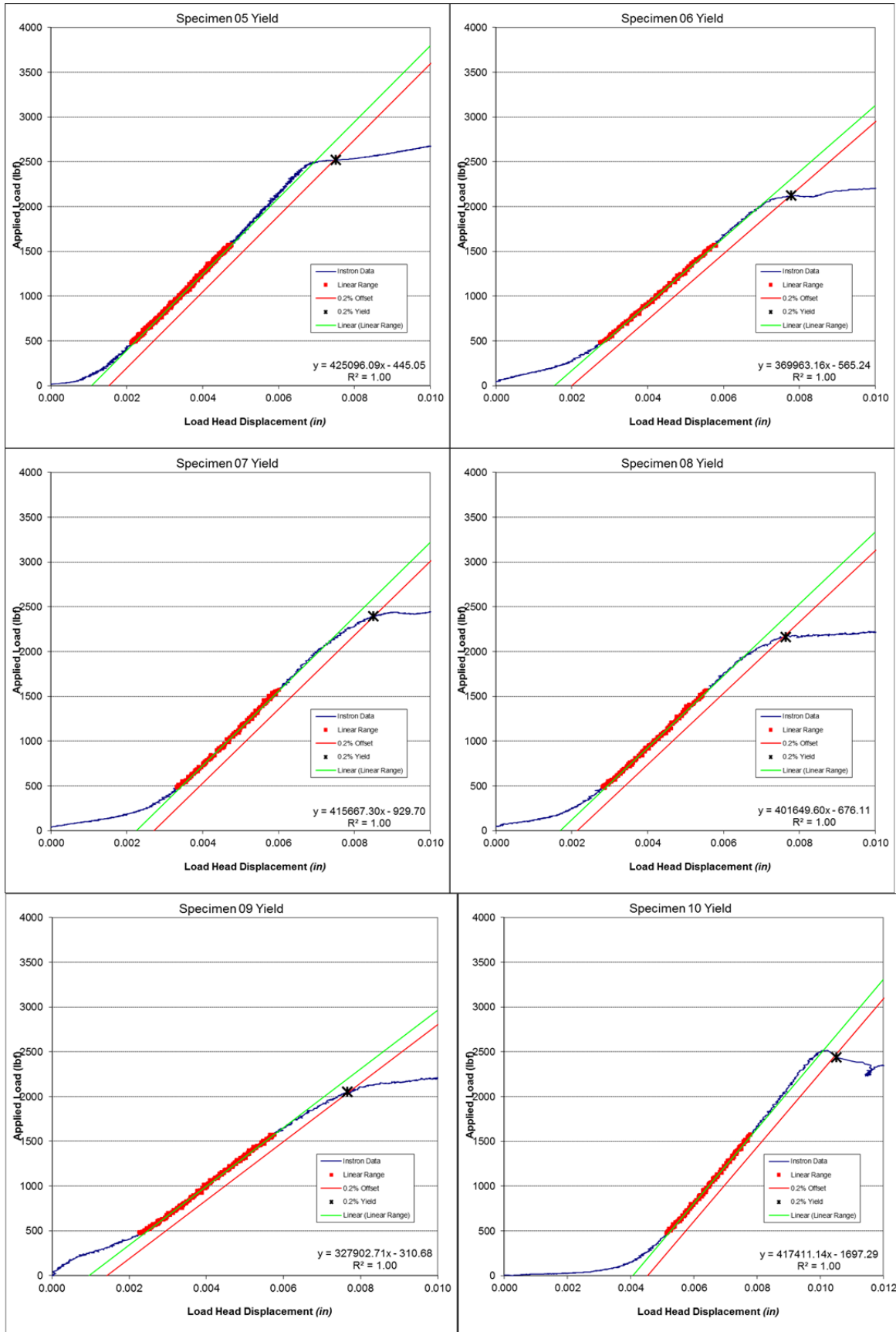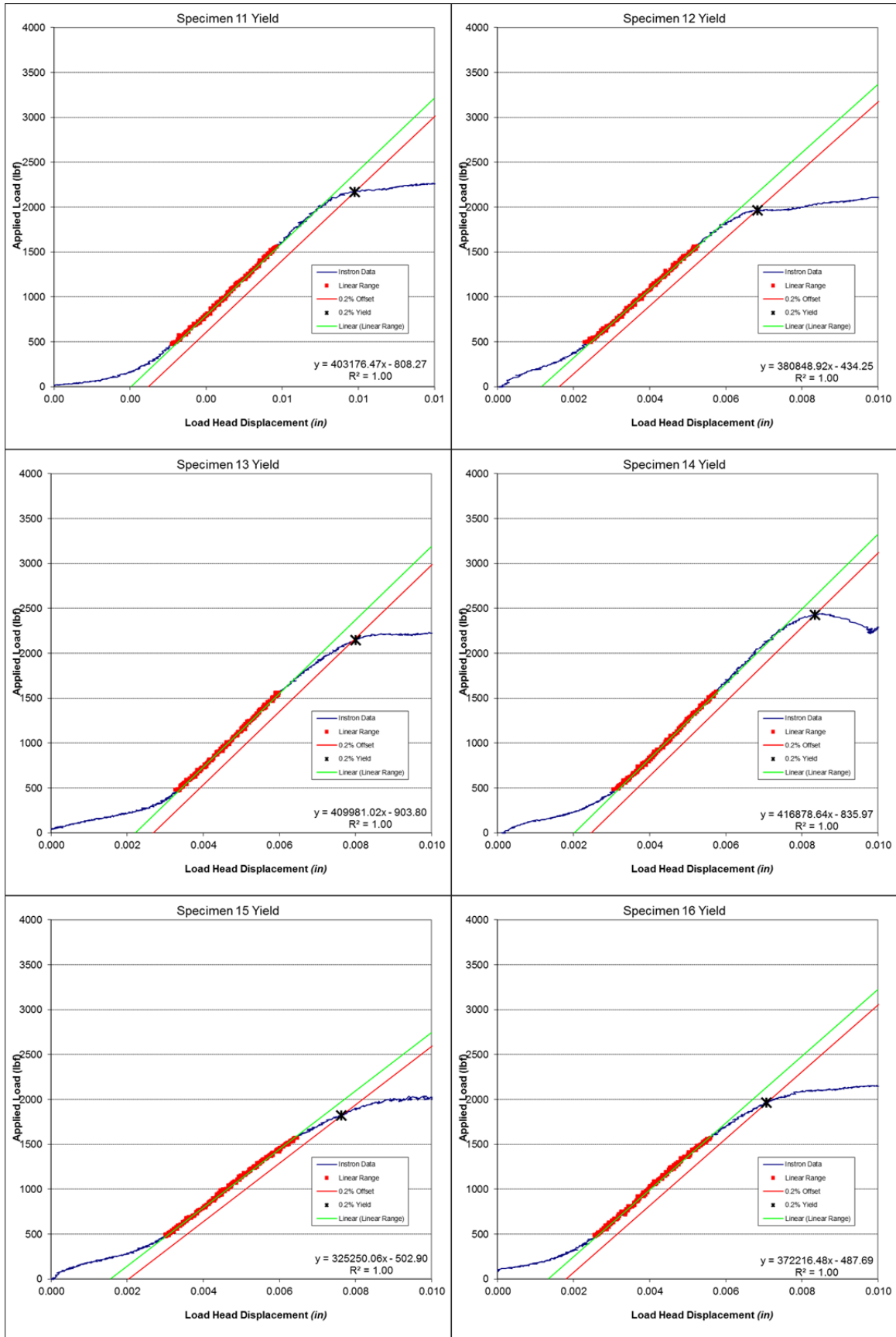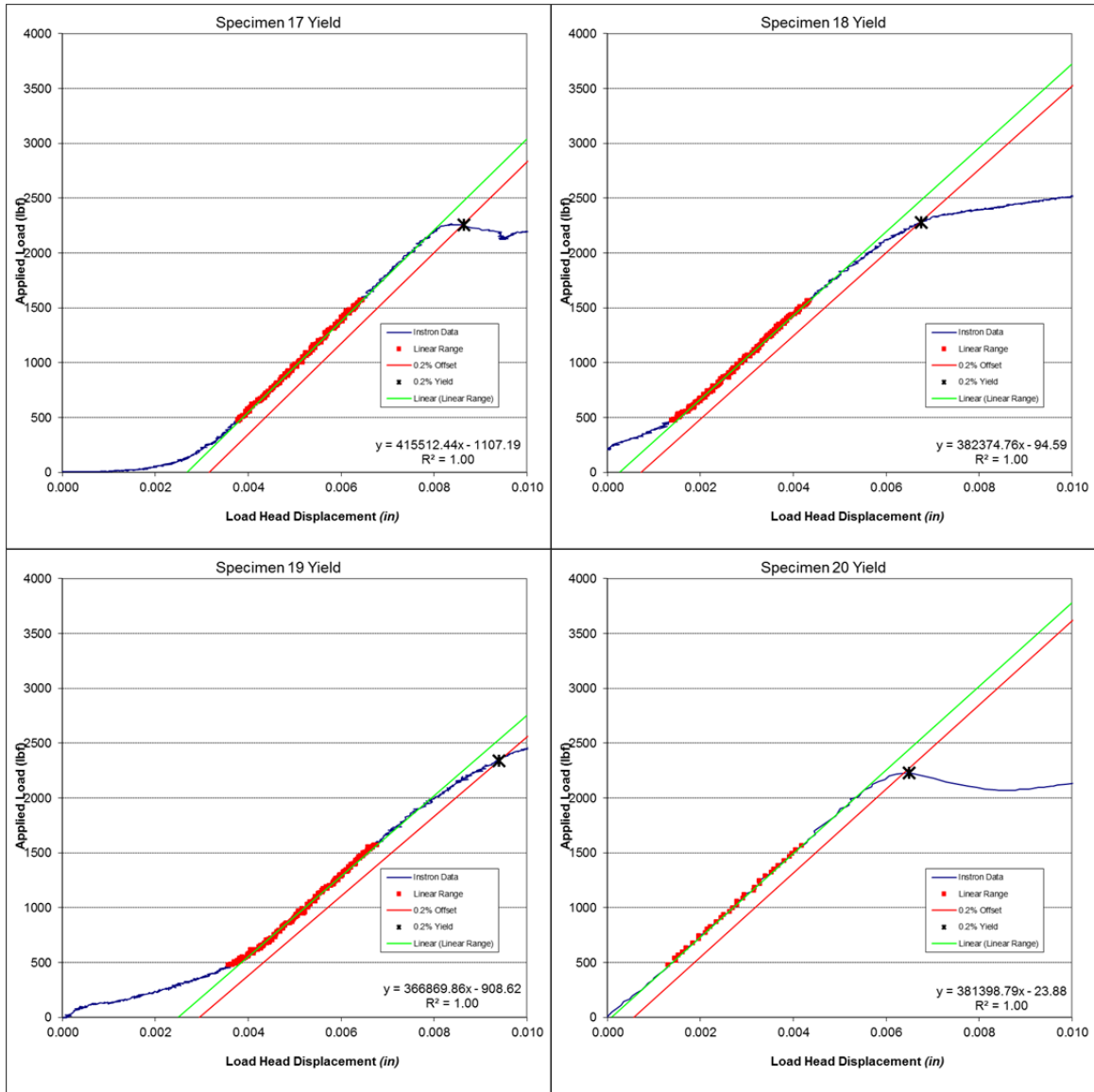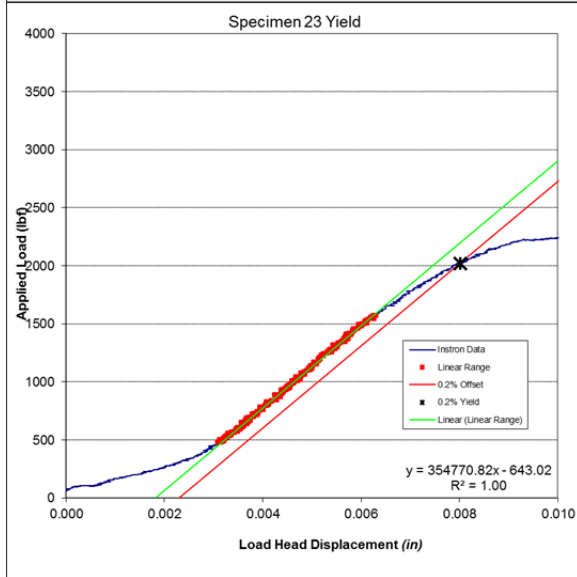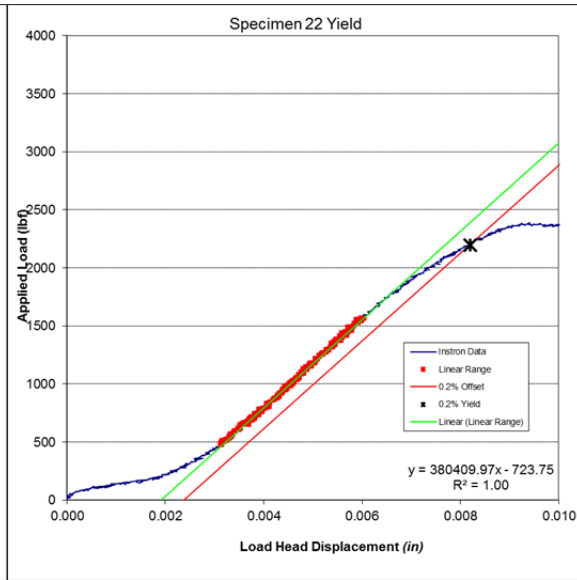## A.4   Load vs. Position Yield Strength Calculation Plots

The plots used to calculate the yield strength of each rivet specimen is provided in this appendix.

Specimen 05 Yield
$y = 425096.09x - 445.05$
$R^2 = 1.00$

Specimen 06 Yield
$y = 369963.16x - 565.24$
$R^2 = 1.00$

Specimen 07 Yield
$y = 415667.30x - 929.70$
$R^2 = 1.00$

Specimen 08 Yield
$y = 401649.60x - 676.11$
$R^2 = 1.00$

Specimen 09 Yield
$y = 327902.71x - 310.68$
$R^2 = 1.00$

Specimen 10 Yield
$y = 417411.14x - 1697.29$
$R^2 = 1.00$

Specimen 11 Yield

$y = 403176.47x - 808.27$
$R^2 = 1.00$

Specimen 12 Yield

$y = 380848.92x - 434.25$
$R^2 = 1.00$

Specimen 13 Yield

$y = 409981.02x - 903.80$
$R^2 = 1.00$

Specimen 14 Yield

$y = 416878.64x - 835.97$
$R^2 = 1.00$

Specimen 15 Yield

$y = 325250.06x - 502.90$
$R^2 = 1.00$

Specimen 16 Yield

$y = 372216.48x - 487.69$
$R^2 = 1.00$

Specimen 17 Yield

$y = 415512.44x - 1107.19$
$R^2 = 1.00$

Specimen 18 Yield

$y = 382374.76x - 94.59$
$R^2 = 1.00$

Specimen 19 Yield

$y = 366869.86x - 908.62$
$R^2 = 1.00$

Specimen 20 Yield

$y = 381398.79x - 23.88$
$R^2 = 1.00$

Specimen 21 Yield

y = 284686.86x + 106.47
R² = 1.00

Specimen 22 Yield

y = 380409.97x - 723.75
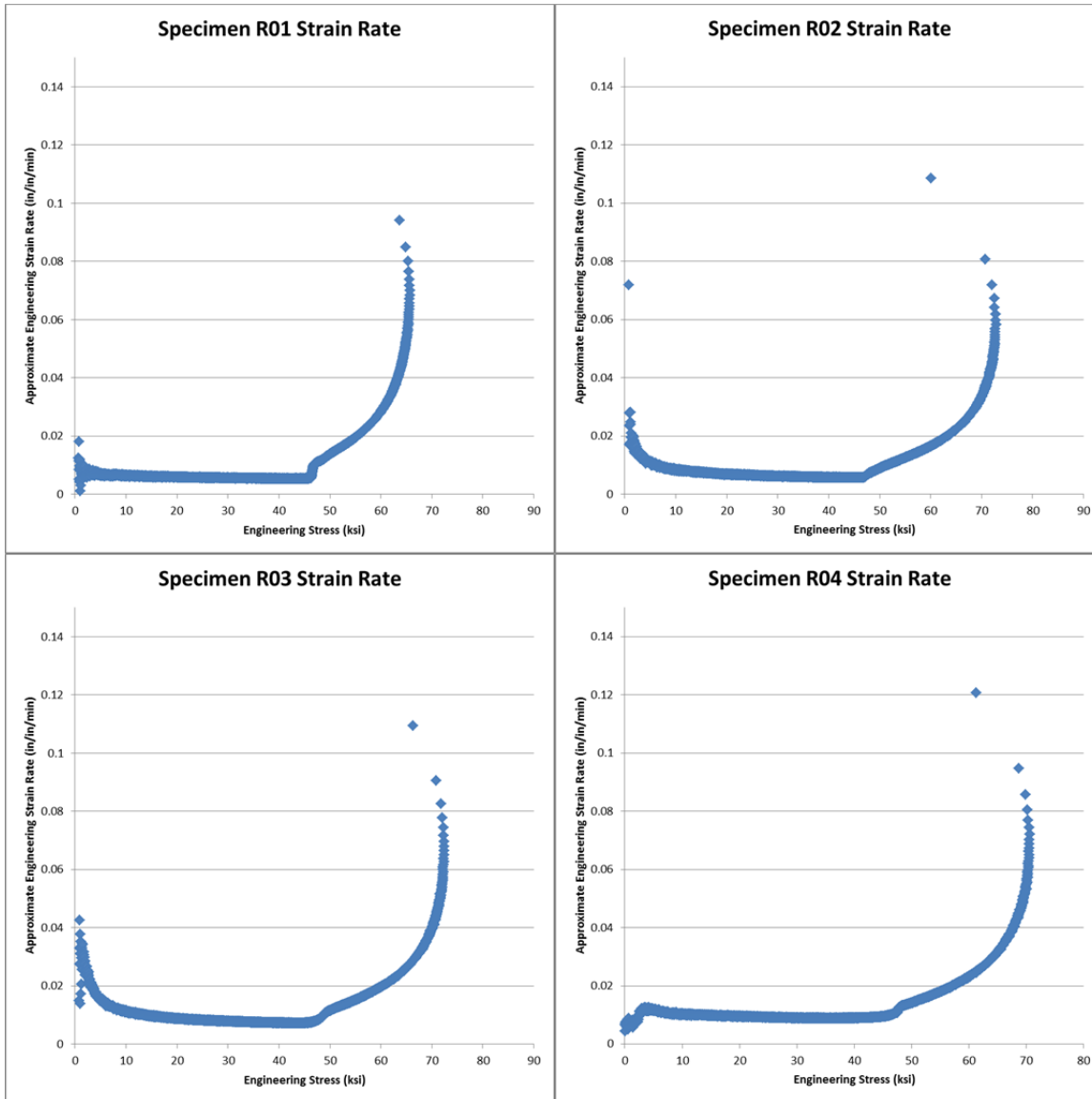R² = 1.00

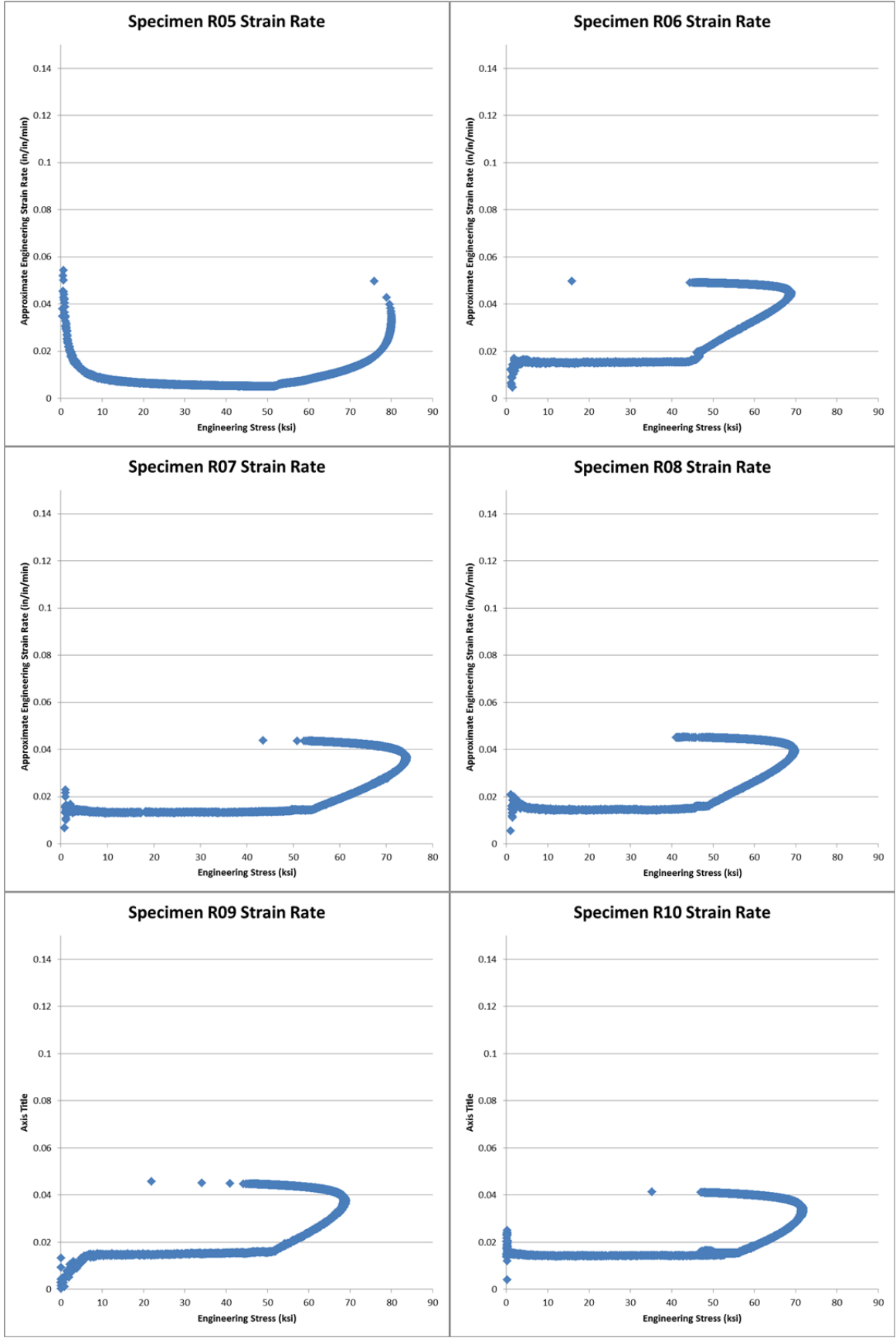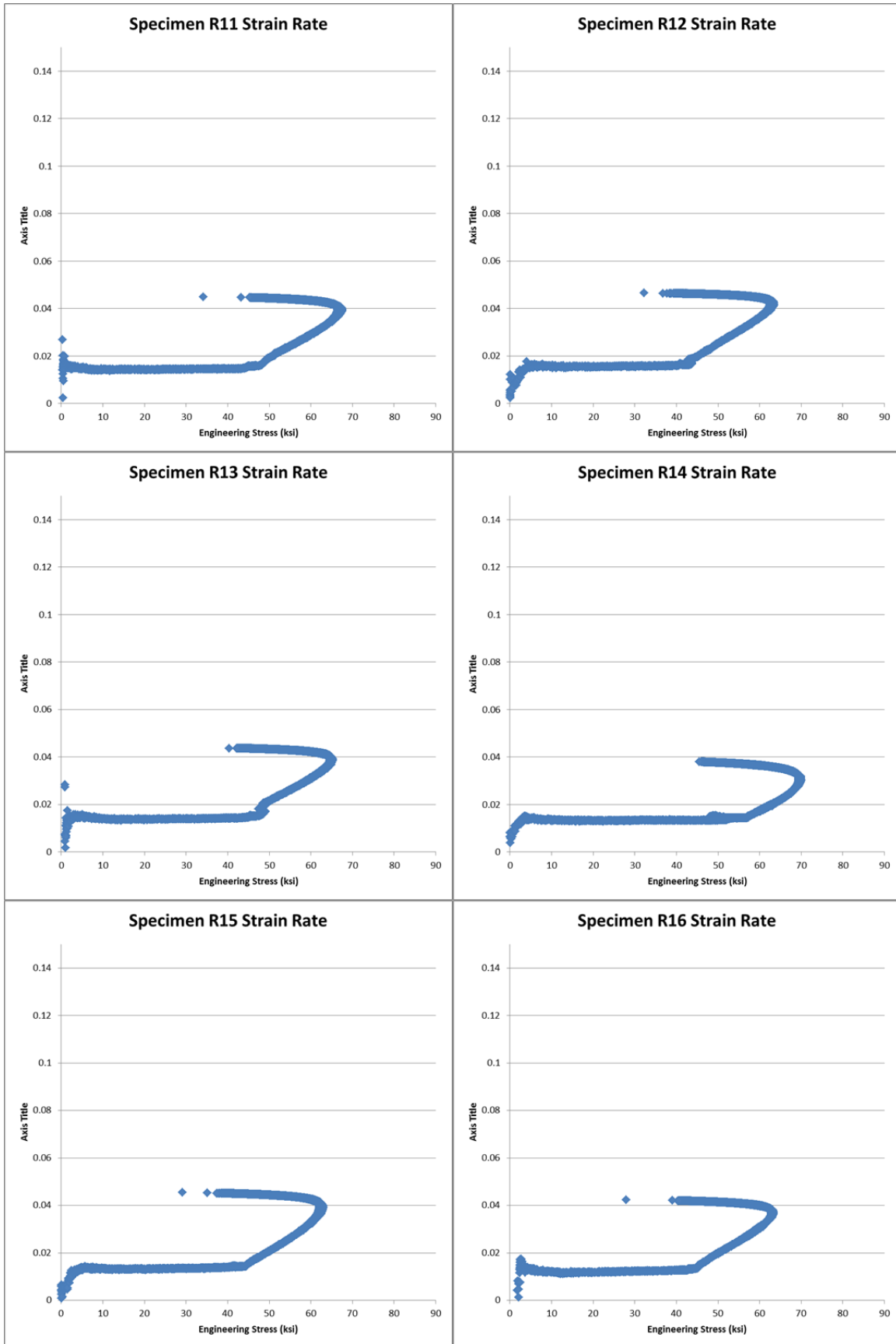Specimen 23 Yield
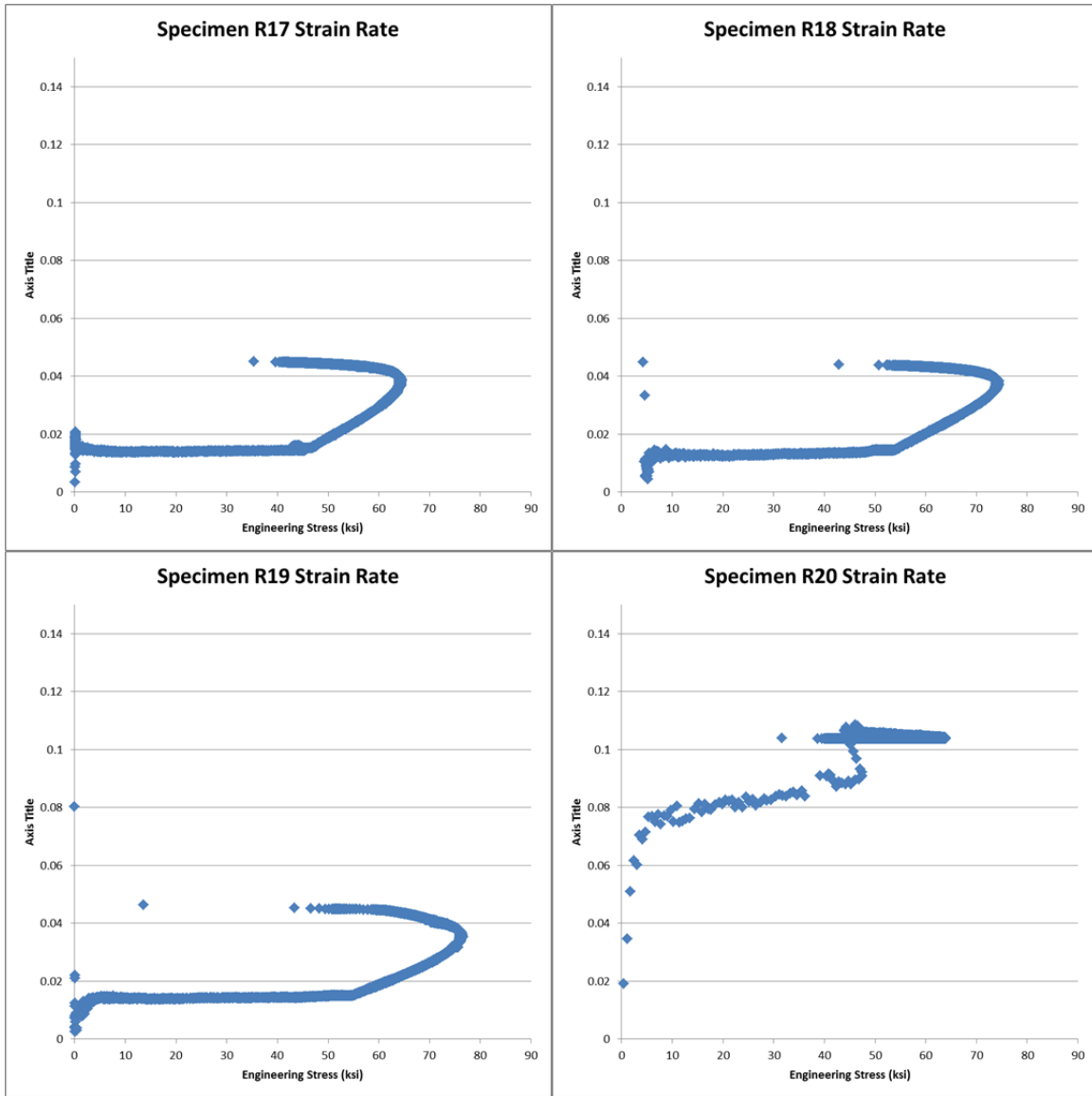
y = 354770.82x - 643.02
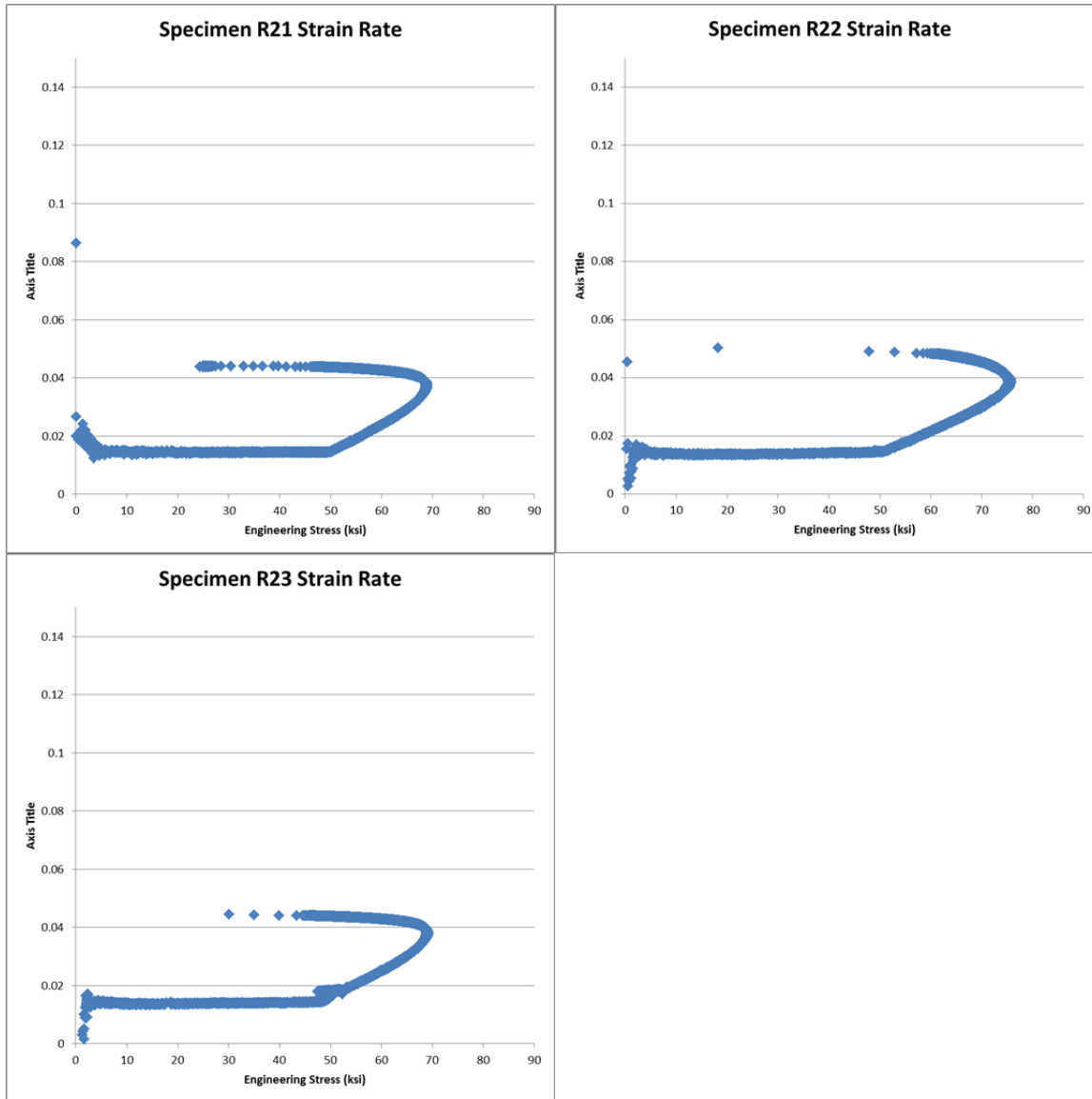R² = 1.00

A.5 Engineering Stress vs. Approximate Engineering Strain Rate

The engineering stress is plotted against the approximate engineering strain rate for each rivet specimen in this appendix.

Specimen R05 Strain Rate

Specimen R06 Strain Rate

Specimen R07 Strain Rate

Specimen R08 Strain Rate

Specimen R09 Strain Rate

Specimen R10 Strain Rate

Specimen R17 Strain Rate

Specimen R18 Strain Rate

Specimen R19 Strain Rate

Specimen R20 Strain Rate

1. ASTM Standard F606/F606M, 2014, "Test Methods for Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, Direct Tension Indicators, and Rivets," ASTM International West Conshohocken, PA, 2014, DOI: 10.1520/F0606_F0606M-14A., www.astm.org.

2. ASTM Standard E8/E8M, 2015, "Test Methods for Tension Testing of Metallic Materials," ASTM International West Conshohocken, PA, 2015, DOI: 10.1520/E0008_E0008M-15A., www.astm.org.

3. AASHTO. (2011) The Manual for Bridge Evaluation. Second Edition ed. Washington DC: AASHTO.