Parallel Plate Test of 36-inch Diameter Steel and Aluminum Pipes

Six metal pipes were tested at the Structures Research Center during May of 2003, 4 steel and 2 aluminum, in accordance with ASTM D2412. Two additional aluminum specimens were tested to adjust the test setup and are not included in the results. All specimens were 8 feet long.

The test setup is as shown in Figure 1 and Figure 2. A pair weights in conjunction with pulleys and cables was used to keep the loading beam and load cells in contact with the actuators. The static loads from this system were zeroed out prior to testing, however, the frictional resistance of the system could not be eliminated in this fashion. This frictional resistance was measured in a couple of dry runs (runs without a pipe specimen) and the resulting resistance subtracted from the resistance measured from the specimen tests.

Figure 1

Figure 2

The pipes were supplied by Contech Construction Products Inc. and were part of their Ultra-Flo Storm Sewer piping line. The steel pipe had an aluminum coating for corrosion protection.

The measured outer diameter of both the aluminum and steel pipes was 35-5/8 inches. This measurement in both cases was to the valleys and did not include the increased diameter due to the ribs. The average measured thickness of the steel pipe was 0.076 inches and the average measured thickness for the aluminum was 0.075 inches.

The pipes were loaded at a constant rate of 0.5 inches per minute. The behavior of both the aluminum and steel pipes was very similar, disregarding their capacity, except that the aluminum ribs would crack at large deflections as shown in Figure 3. The steel ribs did not exhibit any cracking. Both pipes deformed fairly symmetrically except that the side creases were always slightly inclined in an asymmetric fashion as shown in Figure 4. This was probably due to the inclination of the ribs.

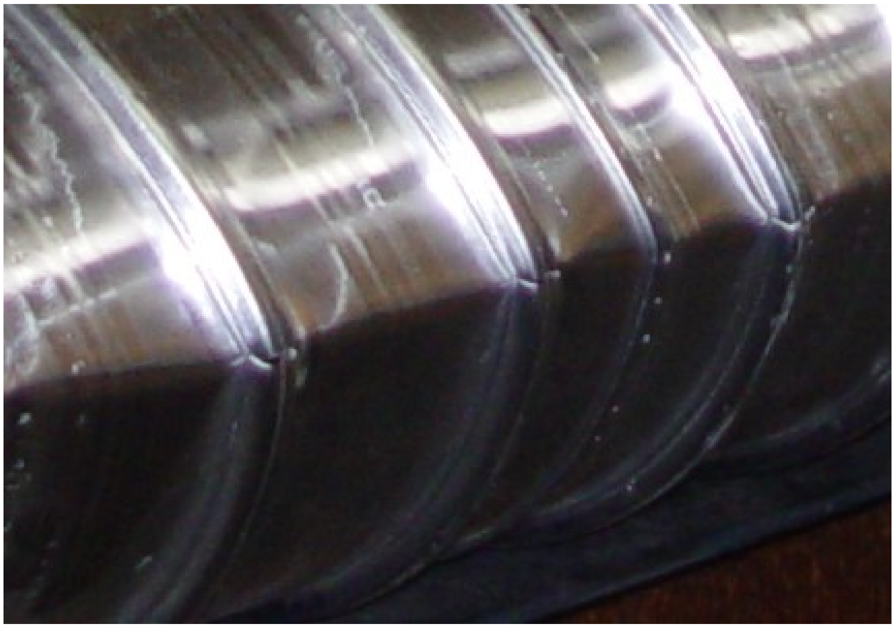
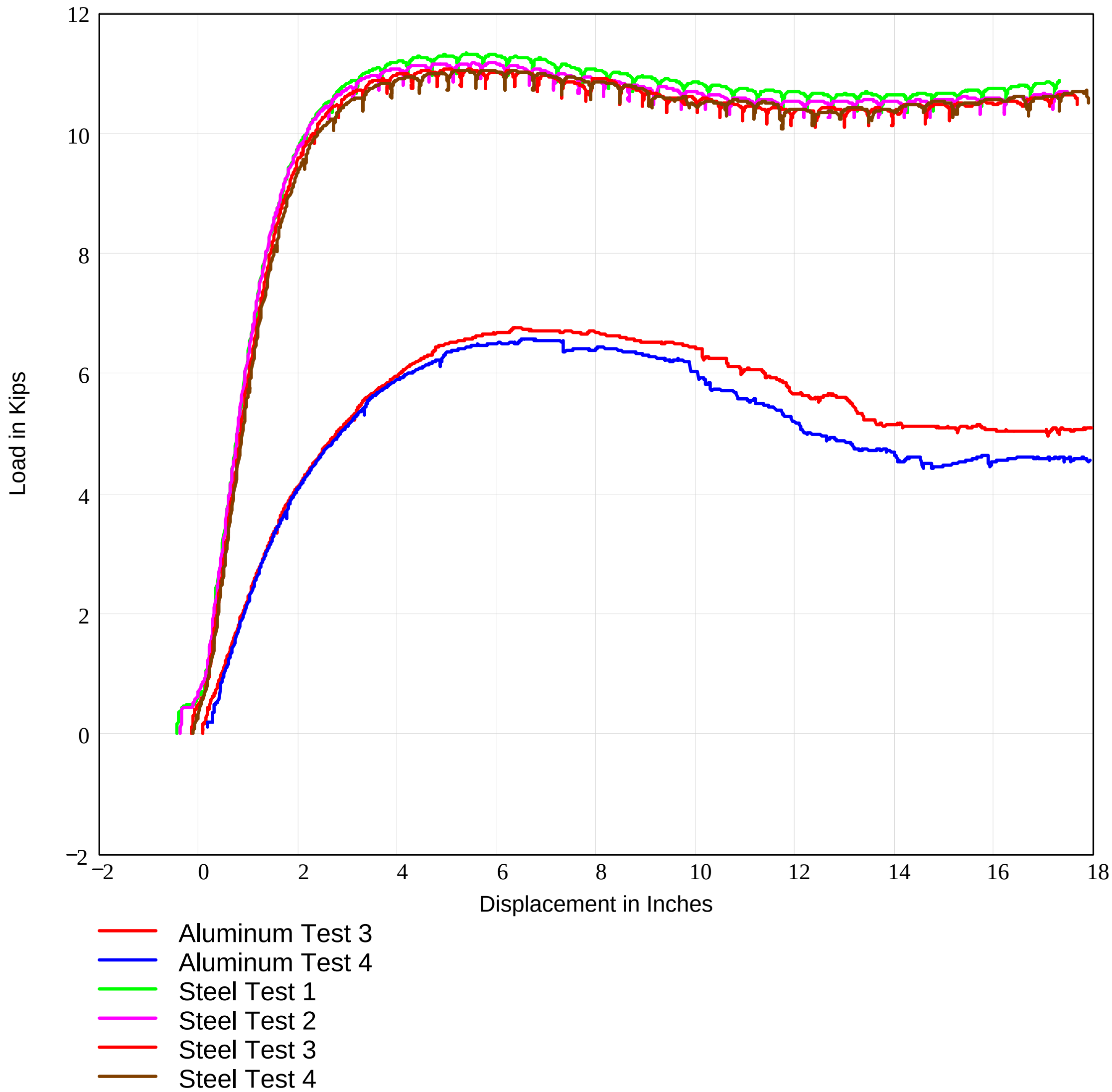


Figure 3

Figure 4

Figure 5 shows the load deflection results for all 6 tests. The deflections have been adjusted to account for the initial offset from a zero intercept but the influence of the dynamic resistance of the loading device is not included. The results of the dry runs that generated the values for this dynamic resistance are shown in Figure 6.



12
10
8
6
4
2
0
−2
Load in Kips
−2
0
2
4
6
8
10
12
14
16
18
Displacement in Inches
Aluminum Test 3
Aluminum Test 4
Steel Test 1
Steel Test 2
Steel Test 3
Steel Test 4

Figure 5

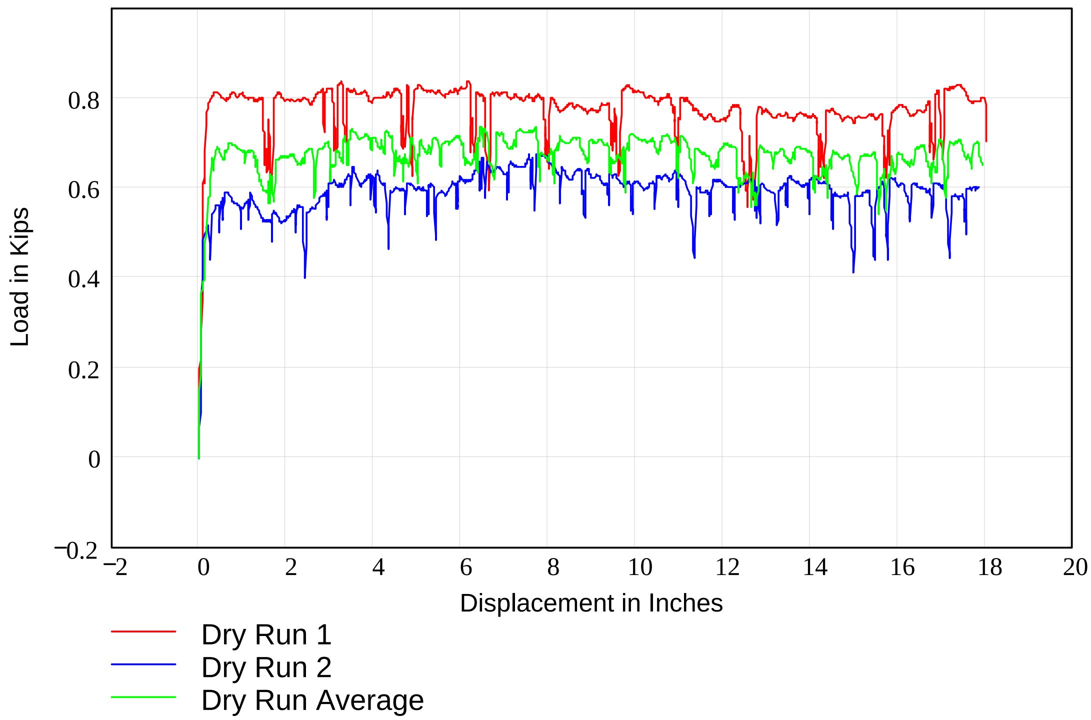


Figure 6

The pipe stiffness was calculated in accordance with ASTM D2412 for deflections of 1 percent and 5 percent of the internal diameter (ignoring the ribs) from the test data. The calculated values are provided in Table 1.

Table 1

Pipe	Pipe Stiffness 1 % Deflection (lbf/in/in)	Pipe Stiffness 5 % Deflection (lbf/in/in)
Aluminum	18.76	22.09
Steel	61.59	53.5

The calculation of these values is included on the following pages.

$kip \equiv 1000 \cdot lbf$

$$\begin{pmatrix} D2_{d1} \\ D2_{d2} \\ D2_{l1} \\ D2_{l2} \end{pmatrix} :=$$

Time	LoadRate_	PID_Loop.	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar
10:29:18 AM	0.05831	5.53842	0	-1.81829	2.96049	-0.01641	-0.00939	0
10:29:19 AM	0.06664	6.75851	0	-1.85007	2.92873	-0.01641	-0.00939	0
10:29:20 AM	0.07497	8.07651	0	-1.86597	2.99225	-0.01592	-0.00939	0
10:29:21 AM	0.0833	9.52569	0	-1.8024	2.96049	-0.01641	-0.00939	0

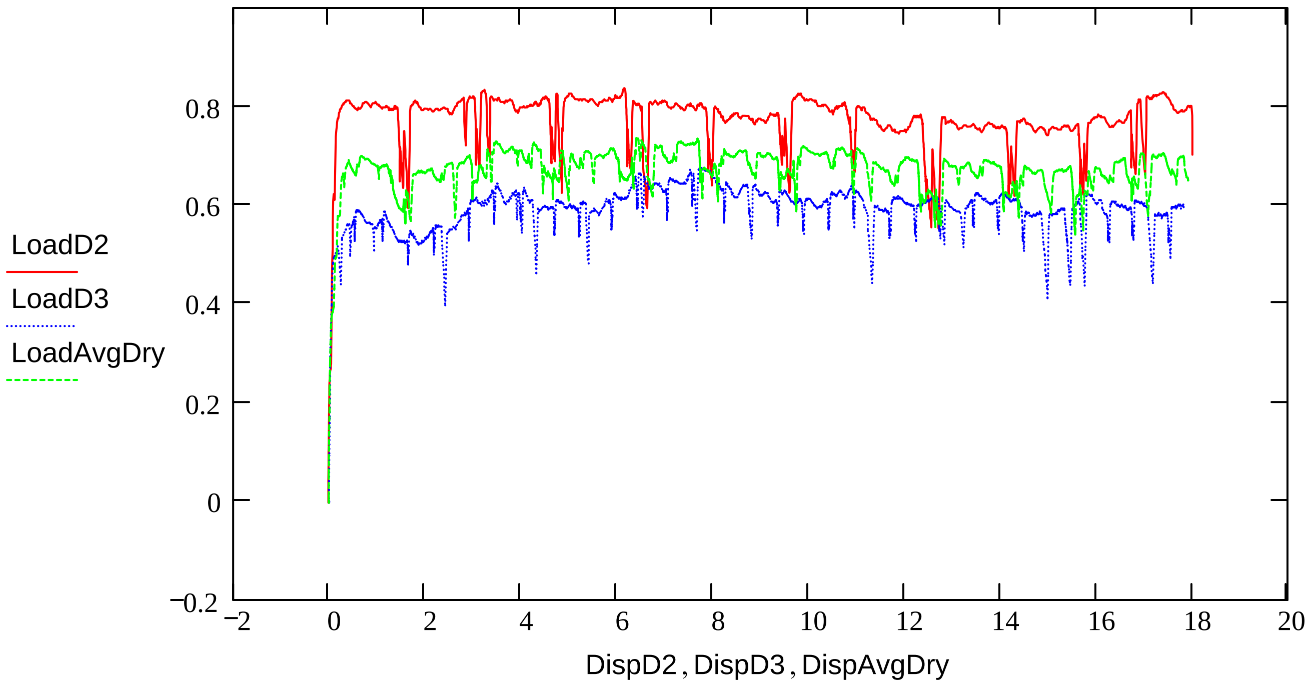
$$\begin{pmatrix} D3_{d1} \\ D3_{d2} \\ D3_{l1} \\ D3_{l2} \end{pmatrix} :=$$

Time	LoadRate_	PID_Loop.	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar
8:39:00 AM	0	0	0	-30.4715	0.18166	-0.00261	0.005876	0
8:39:01 AM	0	0.042542	0	-30.4715	0.18166	-0.00261	0.005876	0
8:39:02 AM	0.00833	0.355182	0	-30.4715	0.134023	-0.00113	0.005876	0
8:39:03 AM	0.01666	1.56653	0	-30.4715	0.149902	-0.00261	0.005876	0

$$DispD2 := \frac{D2_{d1} + D2_{d2}}{2} \qquad LoadD2 := D2_{l1} + D2_{l2}$$

$$DispD3 := \frac{D3_{d1} + D3_{d2}}{2} \qquad LoadD3 := D3_{l1} + D3_{l2}$$

$$DispAvgDry := \frac{DispD2 + DispD3}{2} \qquad LoadAvgDry := \frac{LoadD2 + LoadD3}{2}$$



$PeakD2 := \max(LoadD2)\cdot kip$ $\quad$ $PeakD2 = 0.837\,kip$

$PeakD3 := \max(LoadD3)\cdot kip$ $\quad$ $PeakD3 = 0.675\,kip$

$AvgPeakDryRun := \dfrac{PeakD2 + PeakD3}{2}$ $\quad$ $AvgPeakDryRun = 0.756\,kip$

$$\begin{pmatrix} A3_{d1} \\ A3_{d2} \\ A3_{l1} \\ A3_{l2} \end{pmatrix} :=$$

Time	LVDT1	LVDT2	Loadcell1	Loadcell2
11:31:45 AM	-0.00063	0.004892	0	0
11:31:46 AM	-0.00063	0.004892	0	0
11:31:47 AM	-0.00063	0.005876	0	0

$$\begin{pmatrix} A4_{d1} \\ A4_{d2} \\ A4_{l1} \\ A4_{l2} \end{pmatrix} :=$$

Time	LVDT1	LVDT2	Loadcell1	Loadcell2
1:15:46 PM	0.081227	0.082698	0.140051	-0.03419
1:15:47 PM	0.081227	0.083191	0.140051	-0.03134
1:15:48 PM	0.081227	0.083191	0.140051	-0.03134

$$\begin{pmatrix} S1_{d1} \\ S1_{d2} \\ S1_{l1} \\ S1_{l2} \end{pmatrix} :=$$

Time	LVDT1	LVDT2	Loadcell1	Loadcell2
8:56:00 AM	-0.00014	0.006861	0.002801	0
8:56:00 AM	-0.00014	0.007846	0.002801	0
8:56:00 AM	-0.00014	0.006861	0.002801	0

$$\begin{pmatrix} S2_{d1} \\ S2_{d2} \\ S2_{l1} \\ S2_{l2} \end{pmatrix} :=$$

Time	LVDT1	LVDT2	Loadcell1	Loadcell2
9:55:00 AM	-0.00261	0.005876	0	0
9:55:00 AM	-0.00261	0.006369	-0.0028	0
9:55:00 AM	-0.00113	0.005876	0	0

$$\begin{pmatrix} S3_{d1} \\ S3_{d2} \\ S3_{l1} \\ S3_{l2} \end{pmatrix} :=$$

Time	LoadRate_	PID_Loop.‹	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar	..\MainPar
2:58:08 PM	0	2.8631	0	-30.4715	0.149902	-0.00113	0.006861	-0.0028
2:58:09 PM	0.00833	3.45173	0	-30.4715	0.102265	-0.00113	0.006861	-0.0028
2:58:10 PM	0.01666	5.13993	0	-30.4715	0.134023	-0.00113	0.006861	-0.0028

$$\begin{pmatrix} S4_{d1} \\ S4_{d2} \\ S4_{l1} \\ S4_{l2} \end{pmatrix} :=$$

17.8179	48.3358	143.051	-27.9923	10.8524	17.963	18.0059	5.44797	5.16278
17.8262	34.0342	116.229	-28.2625	10.8047	17.9748	18.0059	5.45357	5.13713
17.8345	19.2542	62.5849	-28.4691	10.8047	17.9748	18.0059	5.45637	5.11719
17.8429	4.72434	0	-28.4691	10.8047	17.9827	18.0068	5.45077	5.10579

$$DispA3 := \frac{A3_{d1} + A3_{d2}}{2}$$

$$LoadA3 := A3_{l1} + A3_{l2}$$

$$DispA4 := \frac{A4_{d1} + A4_{d2}}{2}$$

$$LoadA4 := A4_{l1} + A4_{l2}$$

$$DispS1 := \frac{S1_{d1} + S1_{d2}}{2}$$

$$LoadS1 := S1_{l1} + S1_{l2}$$

$$DispS2 := \frac{S2_{d1} + S2_{d2}}{2}$$

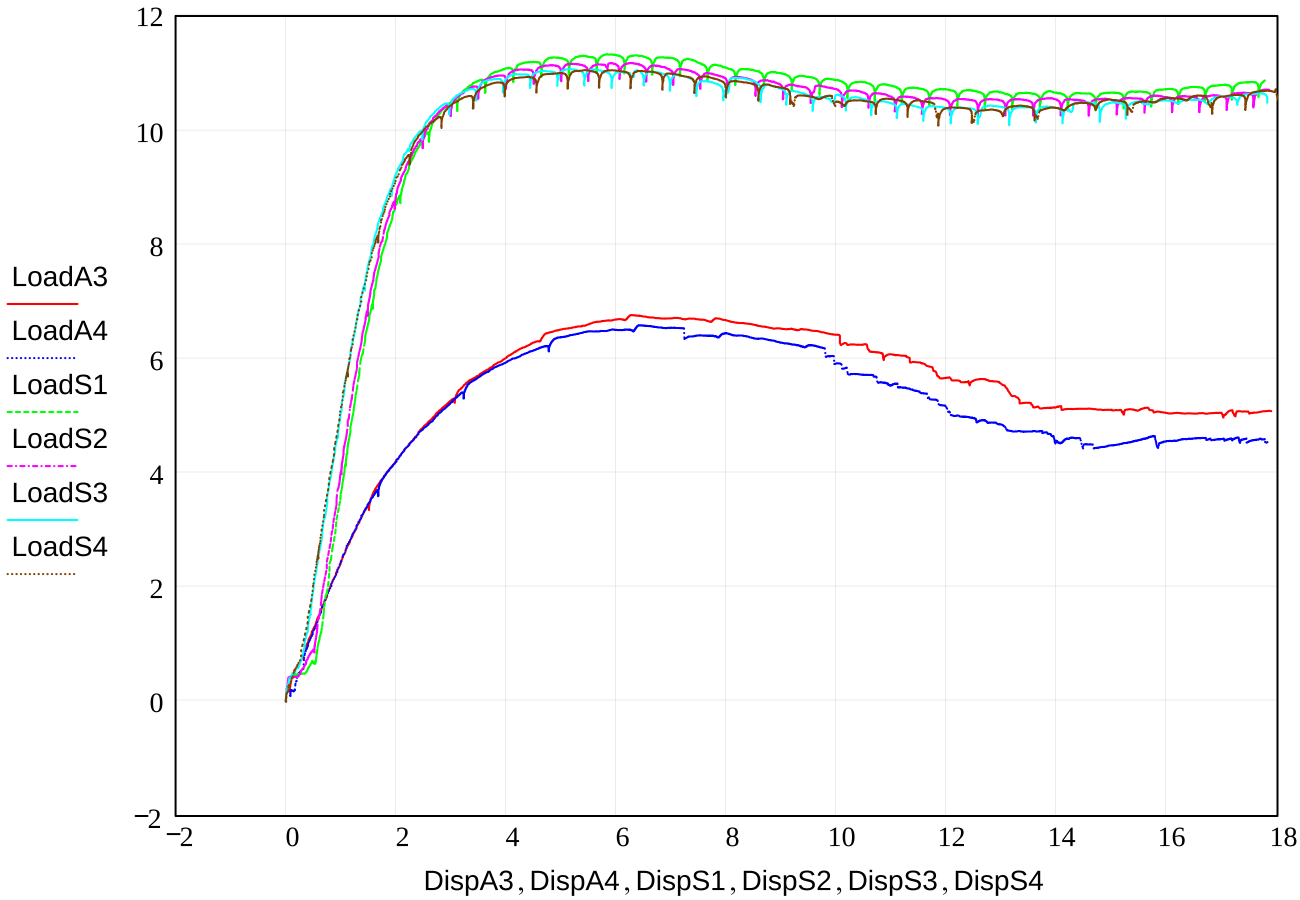
$$LoadS2 := S2_{l1} + S2_{l2}$$

$$DispS3 := \frac{S3_{d1} + S3_{d2}}{2}$$

$$LoadS3 := S3_{l1} + S3_{l2}$$

$$DispS4 := \frac{S4_{d1} + S4_{d2}}{2}$$

$$LoadS4 := S4_{l1} + S4_{l2}$$



$\text{TOL} = 1 \times 10^{-3}$

$\text{TOL} := 0.01$

$\text{A3IndexAt75X} := \text{match}(0.75, \text{DispA3})_0$ $\quad$ $\text{A3LoadAt75X} := \text{LoadA3}_{\text{A3IndexAt75X}}$

$\text{A3DispAt75X} := \text{DispA3}_{\text{A3IndexAt75X}}$

$\text{A3IndexAt125X} := \text{match}(1.25, \text{DispA3})_0$ $\quad$ $\text{A3LoadAt125X} := \text{LoadA3}_{\text{A3IndexAt125X}}$

$\text{A3DispAt125X} := \text{DispA3}_{\text{A3IndexAt125X}}$

$\text{A4IndexAt75X} := \text{match}(0.75, \text{DispA4})_0$ $\quad$ $\text{A4LoadAt75X} := \text{LoadA4}_{\text{A4IndexAt75X}}$

$\text{A4DispAt75X} := \text{DispA4}_{\text{A4IndexAt75X}}$

$A4IndexAt125X := \mathrm{match}(1.25, DispA4)_0$

$A4LoadAt125X := LoadA4_{A4IndexAt125X}$

$A4DispAt125X := DispA4_{A4IndexAt125X}$

$S1IndexAt75X := \mathrm{match}(0.75, DispS1)_0$

$S1LoadAt75X := LoadS1_{S1IndexAt75X}$

$S1DispAt75X := DispS1_{S1IndexAt75X}$

$S1IndexAt125X := \mathrm{match}(1.25, DispS1)_0$

$S1LoadAt125X := LoadS1_{S1IndexAt125X}$

$S1DispAt125X := DispS1_{S1IndexAt125X}$

$S2IndexAt75X := \mathrm{match}(0.75, DispS2)_0$

$S2LoadAt75X := LoadS2_{S2IndexAt75X}$

$S2DispAt75X := DispS2_{S2IndexAt75X}$

$S2IndexAt125X := \mathrm{match}(1.25, DispS2)_0$

$S2LoadAt125X := LoadS2_{S2IndexAt125X}$

$S2DispAt125X := DispS2_{S2IndexAt125X}$

$S3IndexAt75X := \mathrm{match}(0.75, DispS3)_0$

$S3LoadAt75X := LoadS3_{S3IndexAt75X}$

$S3DispAt75X := DispS3_{S3IndexAt75X}$

$S3IndexAt127X := \mathrm{match}(1.27, DispS3)_0$

$S3LoadAt125X := LoadS3_{S3IndexAt127X}$

$S3DispAt125X := DispS3_{S3IndexAt127X}$

$S4IndexAt75X := \mathrm{match}(0.75, DispS4)_0$

$S4LoadAt75X := LoadS4_{S4IndexAt75X}$

$S4DispAt75X := DispS4_{S4IndexAt75X}$

$S4IndexAt125X := \mathrm{match}(1.25, DispS4)_0$

$S4LoadAt125X := LoadS4_{S4IndexAt125X}$

$S4DispAt125X := DispS4_{S4IndexAt125X}$

$$A3Offset := A3DispAt75X - \frac{A3LoadAt75X}{\left(\frac{A3LoadAt125X - A3LoadAt75X}{A3DispAt125X - A3DispAt75X}\right)}$$

$$A4Offset := A4DispAt75X - \frac{A4LoadAt75X}{\left(\frac{A4LoadAt125X - A4LoadAt75X}{A4DispAt125X - A4DispAt75X}\right)}$$

$$S1Offset := S1DispAt75X - \frac{S1LoadAt75X}{\left(\frac{S1LoadAt125X - S1LoadAt75X}{S1DispAt125X - S1DispAt75X}\right)}$$

$$S2Offset := S2DispAt75X - \frac{S2LoadAt75X}{\left(\frac{S2LoadAt125X - S2LoadAt75X}{S2DispAt125X - S2DispAt75X}\right)}$$

$$S3Offset := S3DispAt75X - \frac{S3LoadAt75X}{\left(\frac{S3LoadAt125X - S3LoadAt75X}{S3DispAt125X - S3DispAt75X}\right)}$$

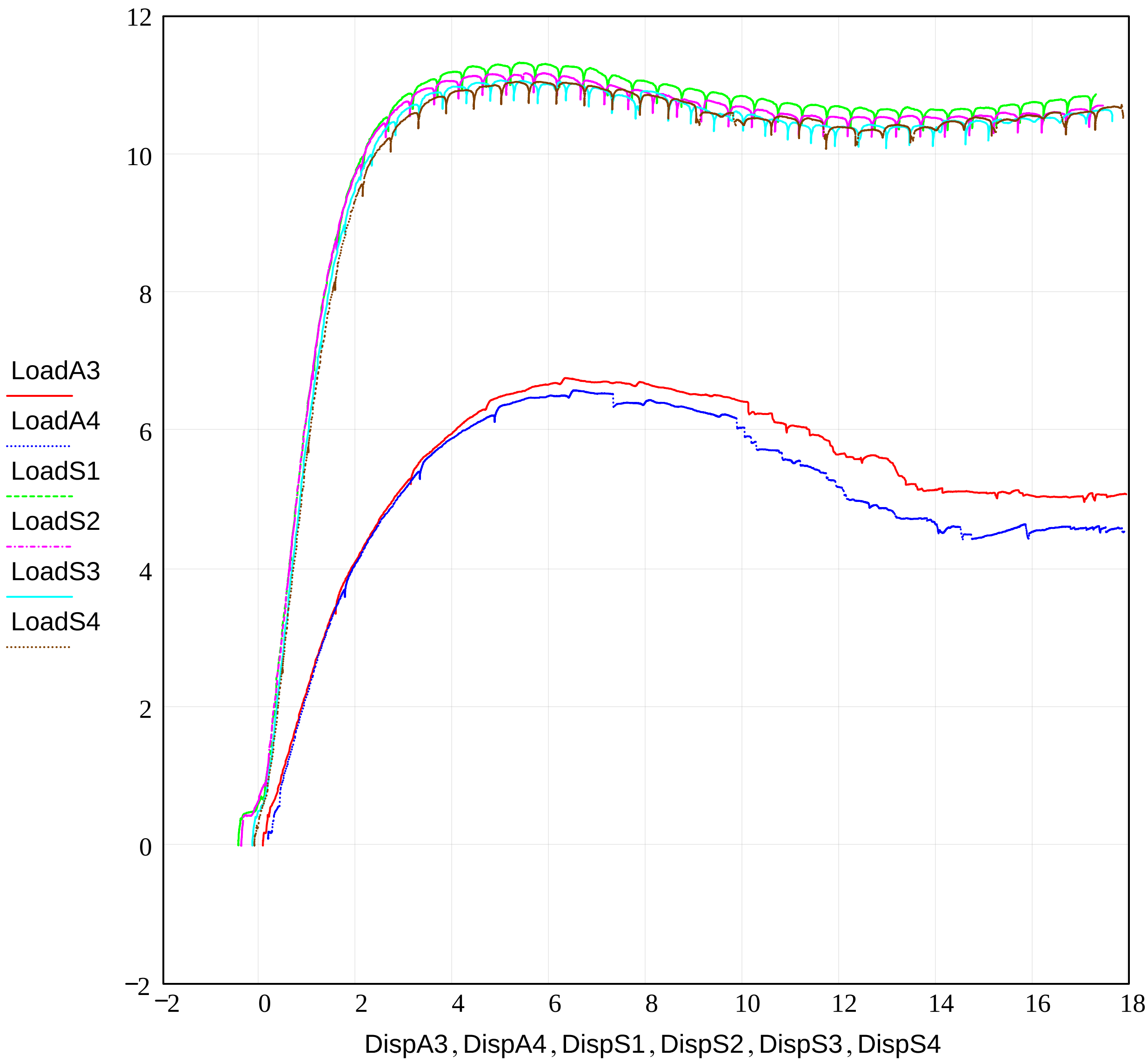
$$S4Offset := S4DispAt75X - \frac{S4LoadAt75X}{\left(\frac{S4LoadAt125X - S4LoadAt75X}{S4DispAt125X - S4DispAt75X}\right)}$$

$DispA3 := DispA3 - A3Offset$ $\quad$ $DispA4 := DispA4 - A4Offset$

$DispS1 := DispS1 - S1Offset$ $\quad$ $DispS2 := DispS2 - S2Offset$

$DispS3 := DispS3 - S3Offset$ $\quad$ $DispS4 := DispS4 - S4Offset$

$TOL := 0.001$



LoadA3
LoadA4
LoadS1
LoadS2
LoadS3
LoadS4
12
10
8
6
4
2
0
−2
−2
0
2
4
6
8
10
12
14
16
18
DispA3 , DispA4 , DispS1 , DispS2 , DispS3 , DispS4

$PeakA3 := \max(LoadA3)\cdot kip$

$PeakIndexA3 := \text{match}\left(\frac{PeakA3}{kip}, LoadA3\right)_0$

$DispPeakA3 := DispA3_{PeakIndexA3}$

$DispPeakA3 = 6.33$

$PeakA4 := \max(LoadA4)\cdot kip$

$PeakIndexA4 := \text{match}\left(\frac{PeakA4}{kip}, LoadA4\right)_0$

$DispPeakA4 := DispA4_{PeakIndexA4}$

$DispPeakA4 = 6.488$

$PeakS1 := \max(LoadS1)\cdot kip$

$PeakIndexS1 := \text{match}\left(\frac{PeakS1}{kip}, LoadS1\right)_0$

$DispPeakS1 := DispS1_{PeakIndexS1}$

$DispPeakS1 = 5.374$

$PeakS2 := \max(LoadS2)\cdot kip$

$PeakIndexS2 := \text{match}\left(\frac{PeakS2}{kip}, LoadS2\right)_0$

$DispPeakS2 := DispS2_{PeakIndexS2}$

$DispPeakS2 = 5.503$

$PeakS3 := \max(LoadS3)\cdot kip$

$PeakIndexS3 := \text{match}\left(\frac{PeakS3}{kip}, LoadS3\right)_0$

$DispPeakS3 := DispS3_{PeakIndexS3}$

$DispPeakS3 = 4.979$

$PeakS4 := \max(LoadS4)\cdot kip$

$PeakIndexS4 := \text{match}\left(\frac{PeakS4}{kip}, LoadS4\right)_0$

$DispPeakS4 := DispS4_{PeakIndexS4}$

$DispPeakS4 = 5.315$

$$\text{AvgAlumPeakLoad} := \frac{\text{PeakA3} + \text{PeakA4}}{2} \qquad \text{AvgAlumPeakLoad} = 6.676\,\text{kip}$$

$$\text{AvgSteelPeakLoad} := \frac{\text{PeakS1} + \text{PeakS2} + \text{PeakS3} + \text{PeakS4}}{4}$$

$$\text{AvgSteelPeakLoad} = 11.157\,\text{kip}$$

$$\text{AvgAlumPeakLoadAdj} := \text{AvgAlumPeakLoad} - \text{AvgPeakDryRun}$$

$$\text{AvgSteelPeakLoadAdj} := \text{AvgSteelPeakLoad} - \text{AvgPeakDryRun}$$

$$\text{AvgAlumPeakLoadAdj} = 5.92\,\text{kip}$$

$$\text{AvgSteelPeakLoadAdj} = 10.4\,\text{kip}$$

$$\text{AvgDispPeakAlum} := \frac{\text{DispPeakA3} + \text{DispPeakA4}}{2} \cdot \text{in}$$

$$\text{AvgDispPeakSteel} := \frac{\text{DispPeakS1} + \text{DispPeakS2} + \text{DispPeakS3} + \text{DispPeakS4}}{4} \cdot \text{in}$$

$$\text{AvgDispPeakAlum} = 6.409\,\text{in}$$

$$\text{AvgDispPeakSteel} = 5.293\,\text{in}$$

$$\text{AvgAlumThk} := \frac{0.0735 + 0.075 + 0.074 + 0.076}{4} \qquad \text{AvgAlumThk} = 0.075$$

$$\text{AvgSteelThk} := \frac{0.0785 + 0.075 + 0.0745 + 0.0745}{4} \qquad \text{AvgSteelThk} = 0.076$$

$$\text{AvgOD} := 35.625$$

$$\text{AvgID} := \text{AvgOD} - 0.075 \cdot 2 \qquad \text{AvgID} = 35.475$$

$\mathsf{OnePercentVal} := \frac{\mathsf{AvgID}}{100}$ $\mathsf{OnePercentVal} = 0.355$

$\mathsf{FivePercentVal} := \frac{\mathsf{AvgID} \cdot 5}{100}$ $\mathsf{FivePercentVal} = 1.774$

$\mathsf{TOL} = 1 \times 10^{-3}$

$\mathsf{TOL} := 0.01$

$\mathsf{A3IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispA3})_0$ $\mathsf{A3IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispA3})_0$

$\mathsf{A4IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispA4})_0$ $\mathsf{A4IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispA4})_0$

$\mathsf{TOL} := 0.02$

$\mathsf{S1IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispS1})_0$

$\mathsf{TOL} := 0.01$

$\mathsf{S1IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispS1})_0$

$\mathsf{S2IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispS2})_0$ $\mathsf{S2IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispS2})_0$

$\mathsf{S3IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispS3})_0$ $\mathsf{S3IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispS3})_0$

$\mathsf{S4IndexAt1} := \mathsf{match}(\mathsf{OnePercentVal}, \mathsf{DispS4})_0$ $\mathsf{S4IndexAt5} := \mathsf{match}(\mathsf{FivePercentVal}, \mathsf{DispS4})_0$

$\mathsf{A3LoadAt1} := \mathsf{LoadA3}_{\mathsf{A3IndexAt1}}$ $\mathsf{A3LoadAt1} = 0.758$

$\mathsf{A3LoadAt5} := \mathsf{LoadA3}_{\mathsf{A3IndexAt5}}$ $\mathsf{A3LoadAt5} = 3.844$

$\mathsf{A4LoadAt1} := \mathsf{LoadA4}_{\mathsf{A4IndexAt1}}$ $\mathsf{A4LoadAt1} = 0.52$

$\mathsf{A4LoadAt5} := \mathsf{LoadA4}_{\mathsf{A4IndexAt5}}$ $\mathsf{A4LoadAt5} = 3.68$

$\mathsf{S1LoadAt1} := \mathsf{LoadS1}_{\mathsf{S1IndexAt1}}$ $\mathsf{S1LoadAt1} = 2.287$

$\mathsf{S1LoadAt5} := \mathsf{LoadS1}_{\mathsf{S1IndexAt5}}$ $\mathsf{S1LoadAt5} = 9.339$

$\mathsf{S2LoadAt1} := \mathsf{LoadS2}_{\mathsf{S2IndexAt1}}$ $\mathsf{S2LoadAt1} = 2.33$

$\mathsf{S2LoadAt5} := \mathsf{LoadS2}_{\mathsf{S2IndexAt5}}$ $\mathsf{S2LoadAt5} = 9.311$

$S3LoadAt1 := LoadS3_{S3IndexAt1}$ $\qquad S3LoadAt1 = 1.985$

$S3LoadAt5 := LoadS3_{S3IndexAt5}$ $\qquad S3LoadAt5 = 8.95$

$S4LoadAt1 := LoadS4_{S4IndexAt1}$ $\qquad S4LoadAt1 = 1.788$

$S4LoadAt5 := LoadS4_{S4IndexAt5}$ $\qquad S4LoadAt5 = 8.837$

$$AvgAlumLoadAt1 := \frac{A3LoadAt1 + A4LoadAt1}{2} \cdot kip \qquad AvgAlumLoadAt1 = 0.639\,kip$$

$$AvgAlumLoadAt5 := \frac{A3LoadAt5 + A4LoadAt5}{2} \cdot kip \qquad AvgAlumLoadAt5 = 3.762\,kip$$

$$AvgStlLoadAt1 := \frac{S1LoadAt1 + S2LoadAt1 + S3LoadAt1 + S4LoadAt1}{4} \cdot kip$$

$$AvgStlLoadAt1 = 2.097\,kip$$

$$AvgStlLoadAt5 := \frac{S1LoadAt5 + S2LoadAt5 + S3LoadAt5 + S4LoadAt5}{4} \cdot kip$$

$$AvgStlLoadAt5 = 9.109\,kip$$

$$AlumPSAt1 := \frac{\frac{AvgAlumLoadAt1}{OnePercentVal \cdot in}}{8 \cdot ft} \qquad AlumPSAt1 = 18.761 \frac{\frac{lbf}{in}}{in}$$

$$AlumPSAt5 := \frac{\frac{AvgAlumLoadAt5}{FivePercentVal \cdot in}}{8 \cdot ft} \qquad AlumPSAt5 = 22.093 \frac{\frac{lbf}{in}}{in}$$

$$SteelPSAt1 := \frac{\frac{AvgStlLoadAt1}{OnePercentVal \cdot in}}{8 \cdot ft} \qquad SteelPSAt1 = 61.587 \frac{\frac{lbf}{in}}{in}$$

$$SteelPSAt5 := \frac{\frac{AvgStlLoadAt5}{FivePercentVal \cdot in}}{8 \cdot ft} \qquad SteelPSAt5 = 53.496 \frac{\frac{lbf}{in}}{in}$$