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Ko, S. K. P.; Molletti, S.; Bishop, M.; Baskaran, B. A.

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SIGDERS Wind Uplift Resistance Data on Mechanically Attached Single Ply Roofing Systems: Effect of Steel Deck Parameters

IRC-RR-217

Ko, K.P. ; Molleti, S. ;

Bishop, M. ; Baskaran, A.

March 2006



National Research
Council Canada

Conseil national
de recherches Canada

Canada

Executive Summary

At the National Research Council of Canada in November 1994, members of the North American roofing community {*manufacturers, building owners, industry association and research agencies*} met and agreed that a means of evaluating the effect of dynamic wind loads on roofing systems was necessary. Thus, a *Special Interest Group on Dynamic Evaluation of Roofing Systems* (SIGDERS) was created. SIGDERS combined the efforts of the National Research Council of Canada with those of the roofing community to design and build a facility and develop a protocol to evaluate the performance of roofing systems under dynamic wind loads. The mandate of SIGDERS is to carry out generic, pre-competitive research of benefit to all its members. Currently, the consortium is in its Phase IV operation.

As part of the Phase IV – Objective 1, *“Influence of steel deck parameters on the wind uplift resistance of mechanically attached roofs”*, investigations were made in the Dynamic Roofing Facility (DRF). Baskaran and Lei (1997) documented the DRF’s features. Systems were subjected to SIGDERS dynamic test protocol as per the CSA123.21 standard (CSA, 2004). In total fifteen systems were investigated. Five systems had poly vinyl chloride (PVC) membranes from two different sources (PVC1 and PVC2). Four systems each had thermoplastic polyolefin (TPOs) membrane and modified bituminous membrane (Mod Bit). Two systems had ethylene propylene diene monomer (EPDM) membrane. All systems had polyisocyanurate insulation and steel deck as system components and some systems also had vapour barrier (retarder).

This report summarizes the wind uplift resistance data in three sections as follows:

1. Influence of Deck Thickness and Tensile Strength (Tables 1 and 2)
2. Influence of Deck Span and Membrane Seam Attachment Parallel and Perpendicular to Deck Flute (Tables 6 and 7)
3. Influence of Deck Attachment (Tables 11 and 12)

This report archives all the measured system response data collected during the experiments in three sections as described above. Each section provides an isometric view of the components used, a table detailing the components’ nominal physical and mechanical properties and a layout of the instrumentation. In addition, each section also groups time history plots for the measured pressure, load and deflection data and photographic records of failure investigation.

Based on the preliminary data analysis, the following observations can be made:

- Increase of steel deck tensile strength and thickness may not increase the wind uplift rating of a system in which the membrane is the weakest link.
- For all system (either changes in the thickness or changes in the tensile strength), the measured deck deflections were greater than that of the allowable.
- Irrespective of the system (PVC or Mod Bit), membrane fastened perpendicular to the steel deck flute performed better than that of the parallel attachment.
- Systems in which the membrane is attached parallel to the steel deck flute resulted in deck failure.
- Steel deck deflections are greater for system for membrane parallel attached than perpendicular ones.
- Systems with steel deck fastened to the joists performed better than the welded ones due to quality variations among welders.
- To minimize the deck deflection, one can fasten the deck on both sides of the top flanges of the metal joist.

The data collected from this study will be further analyzed to enhance the existing wind design guide for roofs with flexible membranes (Baskaran and Smith, 2005). In addition, one can use this data to develop an analytical tool to forecast the wind uplift rating of roof systems.

Acknowledgement

The presented research is being carried out for a consortium - Special Interest Group for Dynamic Evaluation of Roofing Systems (SIGDERS). SIGDERS was formed from a group of partners who were interested in roofing design. These partners included:

Manufacturers: Atlas Roofing Corporation, Canadian General Tower Ltd., Carlisle Syntec Incorporated, GAF Materials Corporation, GenFlex Roofing Systems, Firestone Building Products Co., IKO Industries Ltd., ITW Buildex, Johns Manville, Sarnafil, Soprema Canada and Stevens Roofing Systems, Tremco Inc and Trufast Corporation

Building Owners: Canada Post Corporation, Department of National Defence, Public Works and Government Services Canada.

Industry Associations: Canadian Roofing Contractors' Association, Canadian Sheet Steel Building Institute, National Roofing Contractors' Association and Roof Consultants Institute.

References

Baskaran, A. and Lei, W. (1997), "A New Facility for Dynamic Wind Performance Evaluation of Roofing Systems", *Proceedings of the Fourth International Symposium on Roofing Technology*, NRCA/NIST, Washington, D.C., U.S.A., pp. 168 -179.

Baskaran, A. and Smith, T.L (2005), "A Guide for the Wind Design of Mechanically Attached Flexible Membrane Roofs", www.nrc.gc.ca/virtualstore.

CSA A123.21-04 (2004), "Standard Test Method for the Dynamic Wind Uplift Resistance of Mechanically Attached Membrane Roofing System", www.csashop.ca.

PART - A
Wind Uplift Resistance Data - Influence of Deck Thickness and Tensile Strength

Table 1: Wind Uplift Resistance Data - Influence of Deck Thickness and Tensile Strength (Imperial Units)

System	Sustained Pressure (psf)	Sustained Load (lbf)	Membrane / Deck Deflection (in)	Failure Mode
System 1 (050303) Pt=60psf 22 Ga *(33/55 ksi), TPO – 76", One Sided Weld, No Barrier, Barbed Metal Plate, #15 Fastener	75	329 / 510**	N/A	Membrane tear
System 2 (011139) Pt=60psf Same as the System 1 with 22 Ga *(80/101 ksi)	90	342 / 683 **	N/A	Membrane tear
System 3 (040107) Pt=90psf 22 Ga *(80/101 ksi), TPO – 76", Double Sided Weld, 6 mil Poly as Barrier, 1/2" Gypsum Board, Polymer Batten Strip, #15 fastener	157	640 / 700 **	N/A	Membrane fastener pullout
System 4 (040209) Pt=90psf Same as the system 3 with 20 Ga *(80/107 ksi)	180	700 / 893 **	N/A	Passed P ¹⁸⁰ - No failure observed
System 5 (060318) Pt=60psf 22 Ga *(33/55 ksi), Mod. Bit. Sopra Vapor as Barrier, base sheet attached at 6" o/c with metal Plate, #14 Fastener and Cap sheet torched.	90	139 / 382**	3.96 / 0.599	Seam delamination
System 6 (060319) Pt=90psf Same as the System 5 with 20 Ga *(33/52 ksi)	Failed at Seq. 6, Level A	N/A	N/A	Seam delamination

All systems had 2" ISO and deck was fastened to joists at 6' o/c

* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

Table 2: Wind Uplift Resistance Data - Influence of Deck Thickness and Tensile Strength (SI Units)

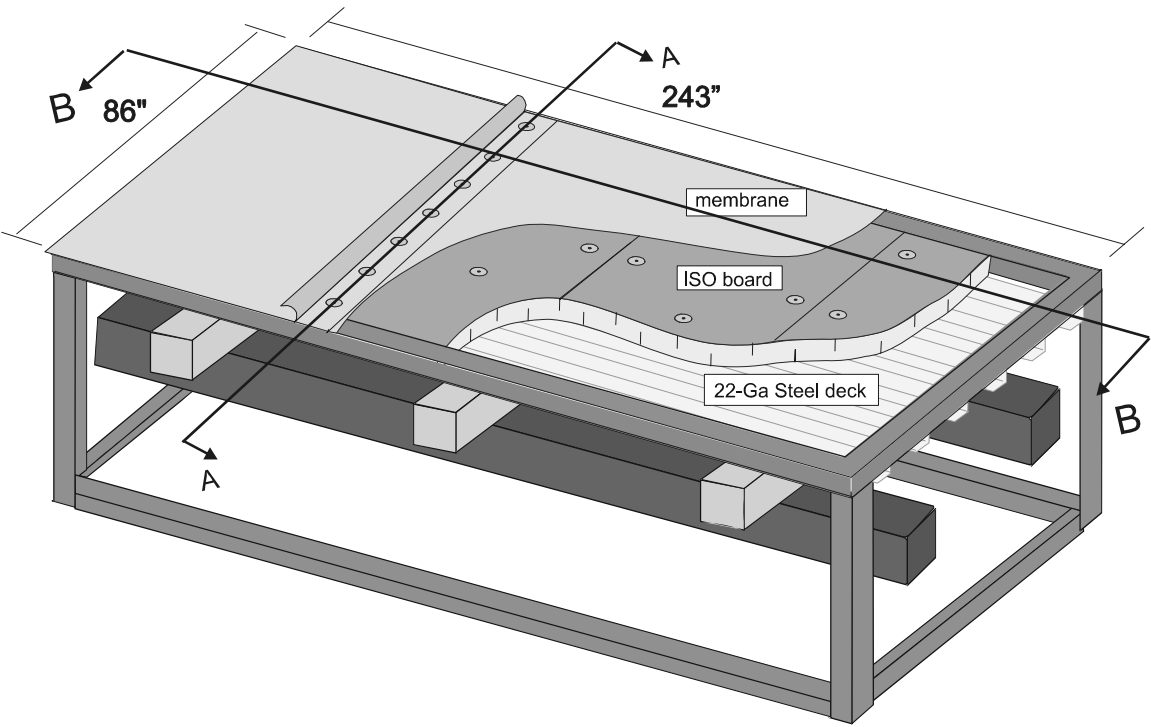
System	Sustained Pressure (Pa)	Sustained Load (N)	Membrane / Deck Deflection (mm)	Failure Mode
System 1 (050303) Pt=2873Pa 22 Ga *(230/380 Mpa), TPO – 1930 mm, One Sided Weld, No Barrier, Barbed Metal Plate, #15 Fastener	3590	1448 / 2244**	N/A	Membrane tear
System 2 (011139) Pt=2873Pa Same as system 1 with 22 Ga *(550/700 Mpa)	4309	1505 / 3005 **	N/A	Membrane tear
System 3 (040107) Pt=4309Pa 22 Ga *(550/700 Mpa), TPO – 1930 mm, Double Sided Weld, 6 mil Poly as Barrier, 12mm Gypsum Board, Polymer Batten Strip, #15 Fastener	7517	2816 / 3080 **	N/A	Membrane fastener pullout
System 4 (040209) Pt=4309Pa Same as system 3 with 20 Ga *(550/740 Mpa)	8618	3080 / 3929 **	N/A	Passed P ¹⁸⁰ - No failure observed
System 5 (060318) Pt=2873Pa 22 Ga *(230/380 Mpa), Mod. Bit. Sopra Vapor as Barrier, base sheet attached at 152mm o/c with metal Plate, #14 Fastener and Cap sheet torched.	4309	611 / 1681**	100.58 / 15.21	Seam delamination
System 6 (060319) Pt=4309Pa Same as the System 5 with 20 Ga *(230/359 Mpa)	Failed at Seq. 6, Level A	N/A	N/A	Seam delamination

All systems had 50 mm ISO and deck was fastened to joists at 1830 mm o/c

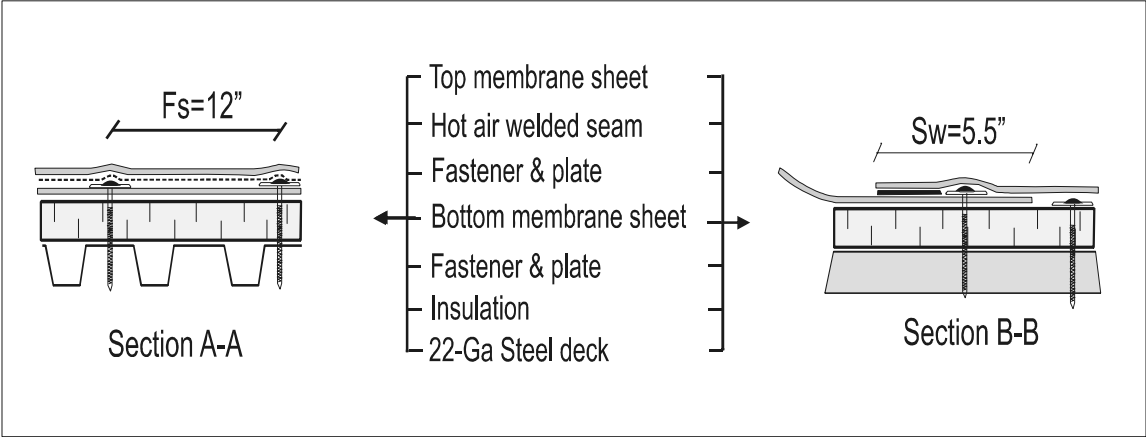
* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

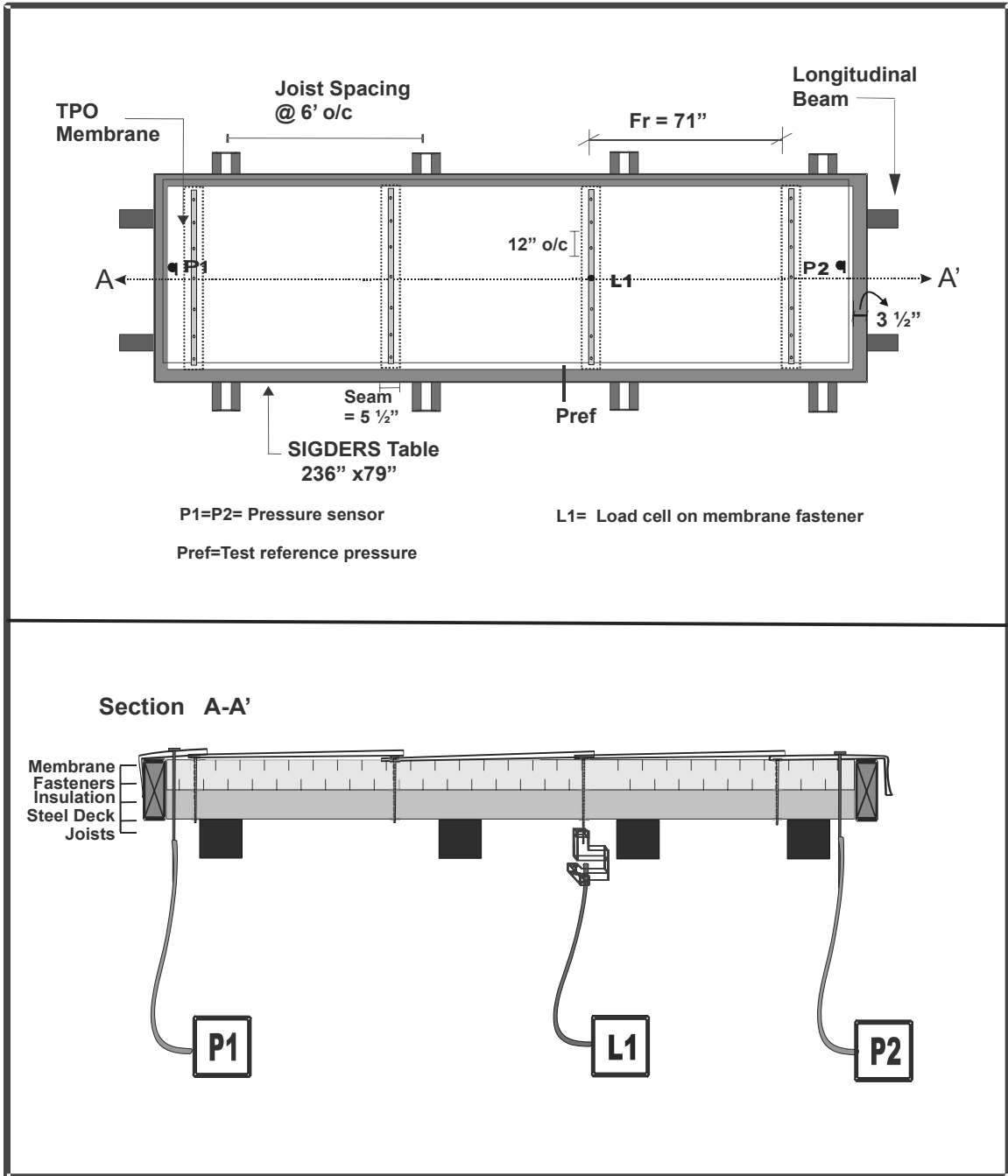
System 1 & 2- Components Layout



System 1: 22-Ga (33/55ksi); System 2: 22-Ga (80/101 ksi)



System 1 & 2 – Instrumentation Layout



System 1 & 2 – Installation



System 1:
Deck Installation: 22 Ga (33 ksi)



System 2:
Deck Installation: 22 Ga (80 ksi)



Membrane Welding



Membrane Attachment



Completed System

Table 3: Nominal physical and mechanical properties of the components for System 1 & System 2

Deck

Type	Profiled 22 gauge metal
Thickness	System 1: 22 Ga (33 / 52 ksi), 0.03" (0.76 mm), nominal; 0.80 mm, measured System 2: 22 Ga (80 / 101 ksi), 0.03" (0.76 mm), nominal; 0.74 mm, measured
Overall Depth	1 1/2 " (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2004	System 1 : 22 Ga (33 / 55 ksi) = 510 lbf (2268 N) System 2 : 22 Ga (80 / 101 ksi) = 683 lbf (3034 N)
Source	System 1: Vicwest Steel System 2: Canam Steel

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 8 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Exeltherm	

Air/Vapor Barrier/Retarders/Support Board

Type None	

Membrane

Type										
Width TPO,										
Thickness	76" (1930 mm)									
Tensile Property as per ASTM D 751*	45 mil (1.1 mm)									
	<table border="0"> <tr> <td></td> <td align="center">MD</td> <td align="center">XD</td> </tr> <tr> <td>Breaking strength, KN (lbf)</td> <td align="center">0.89 (200)</td> <td align="center">0.67(151)</td> </tr> <tr> <td>Elongation at Max. Load, %</td> <td align="center">35</td> <td align="center">30.5</td> </tr> </table>		MD	XD	Breaking strength, KN (lbf)	0.89 (200)	0.67(151)	Elongation at Max. Load, %	35	30.5
	MD	XD								
Breaking strength, KN (lbf)	0.89 (200)	0.67(151)								
Elongation at Max. Load, %	35	30.5								

Attachment

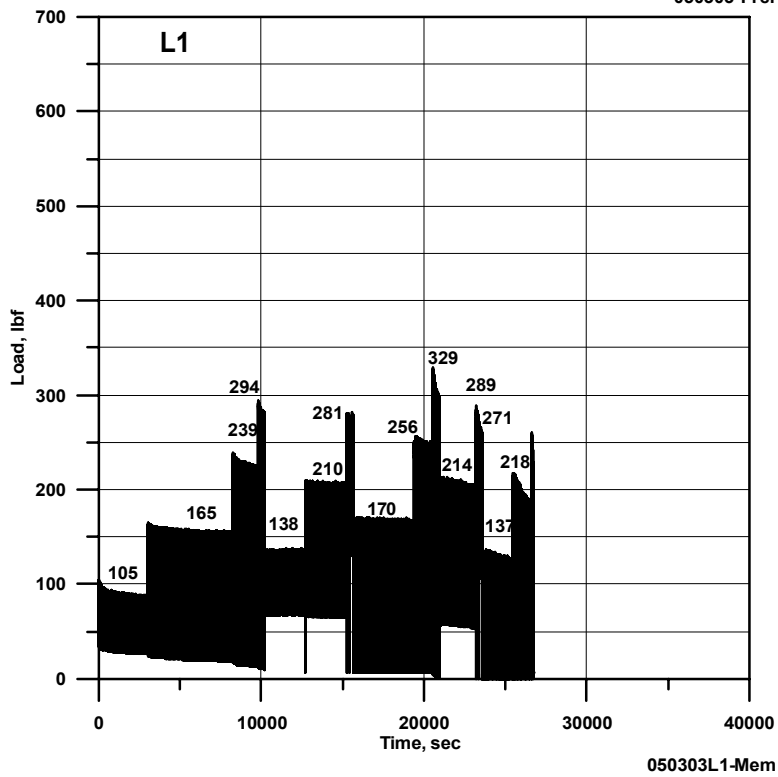
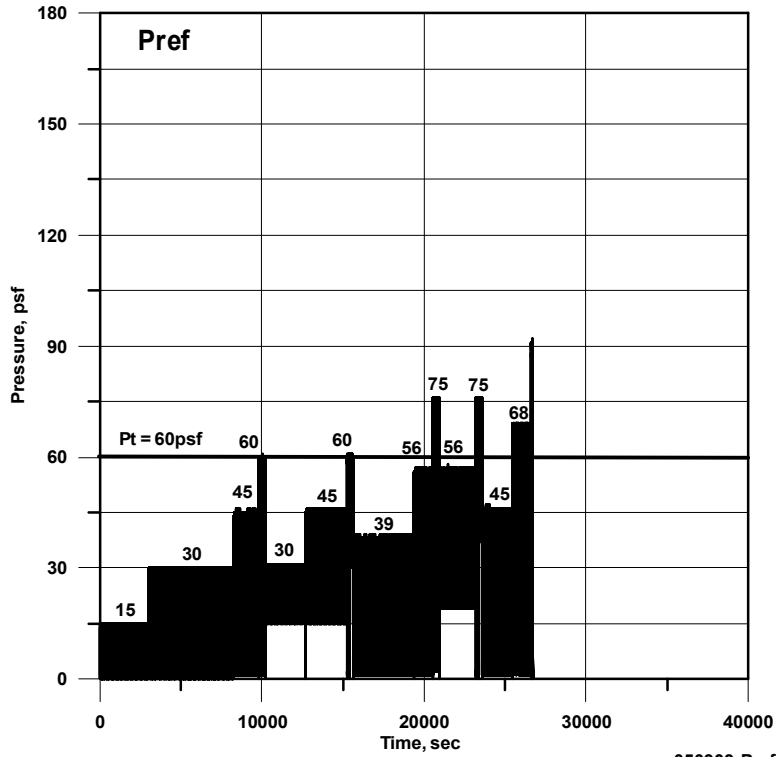
Type	
Fastener	Mechanical fasteners with plates
Plate	5" (128mm), # 15
Fastener Row Spacing	2 3/8" (60.3 mm) dia. Barbed Metal Plate
Fastener Spacing	71" (1803 mm)
Slippage Control	12" (305 mm)
	Yes

Seam

Type	Hot air welding (One Side Weld)
Seaming Width	Overlap = 5 1/2 " (140 mm) Temperature: 540°C Speed: 3.1m/min

* NRC Test Results

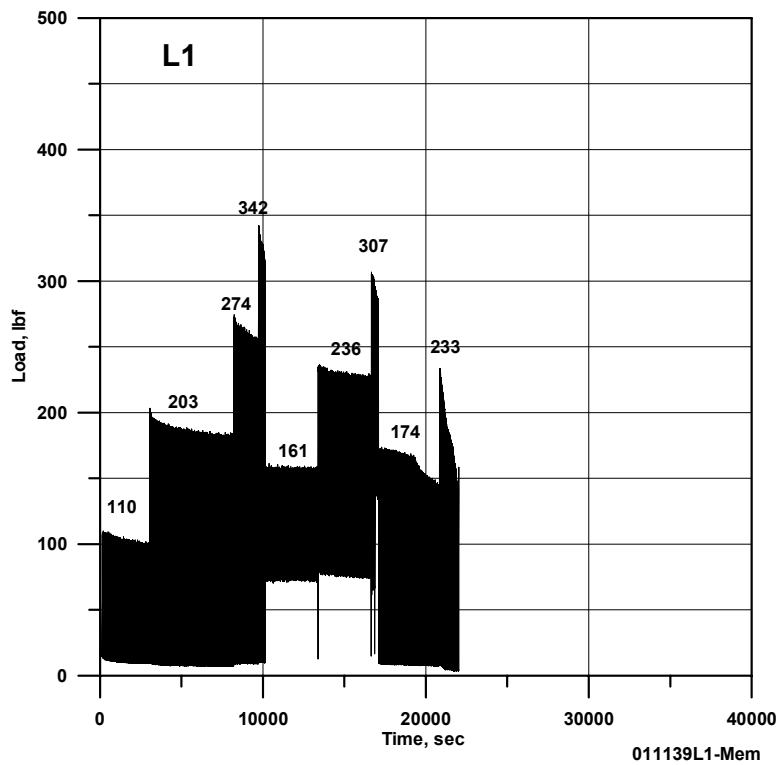
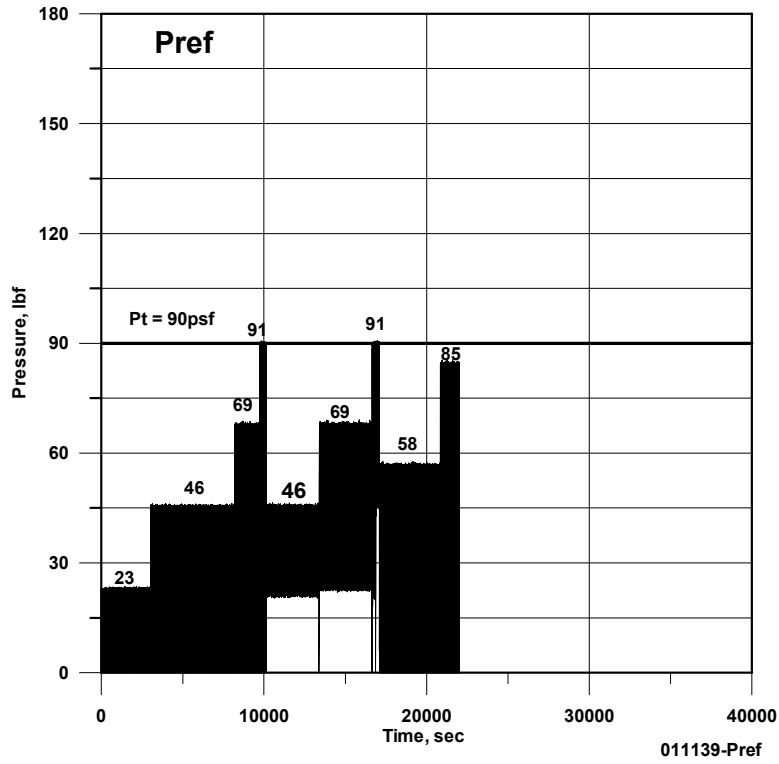
System 1 – Measured Time Histories



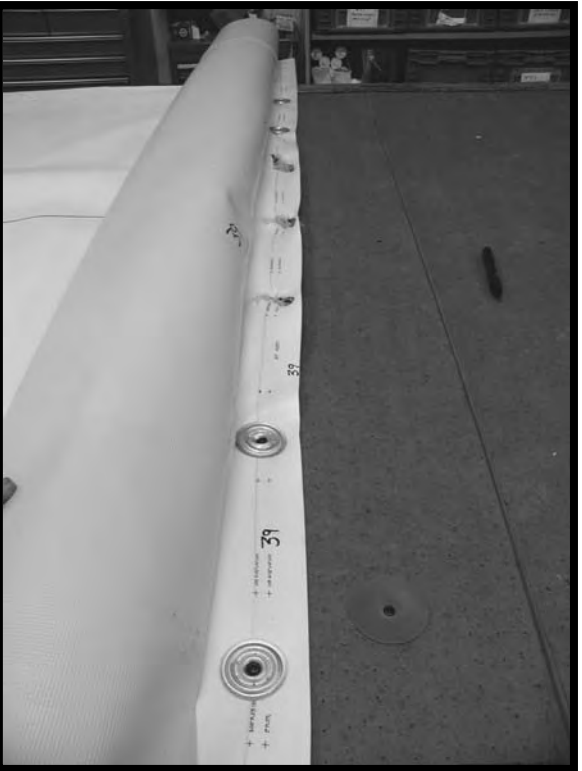
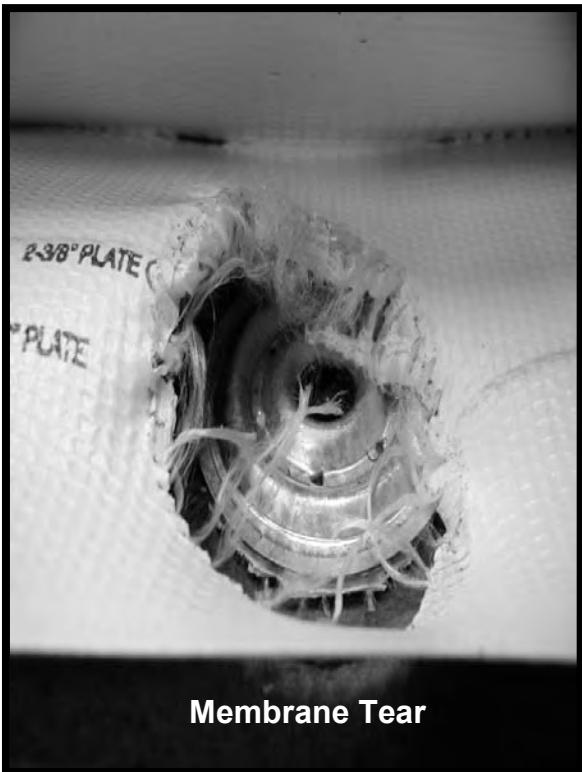
System 1 – Failure Mode



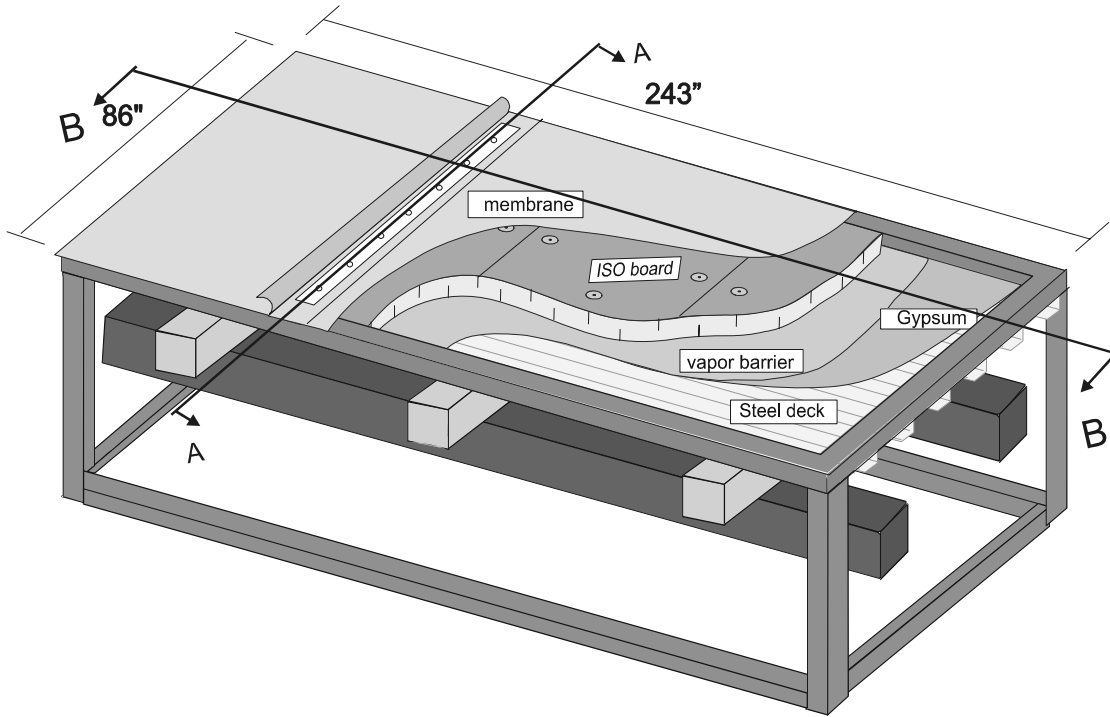
System 2 – Measured Time Histories



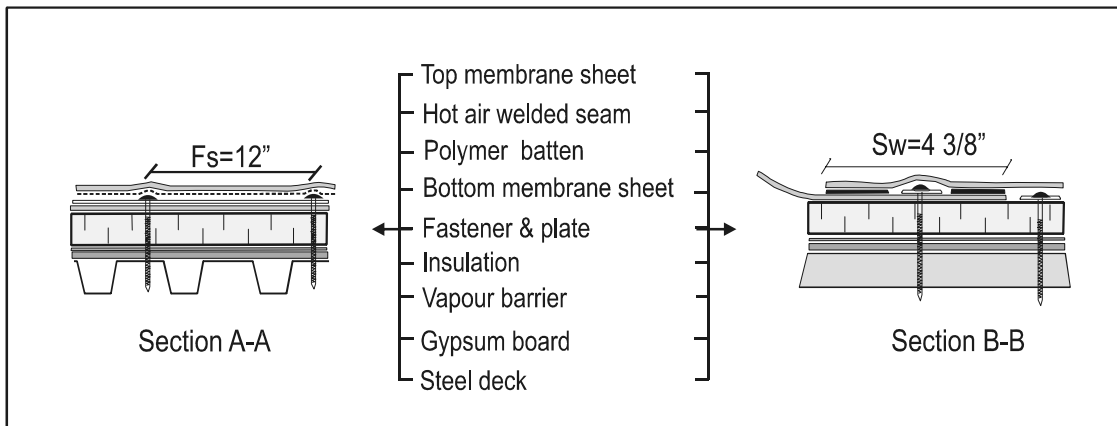
System 2 – Failure Mode



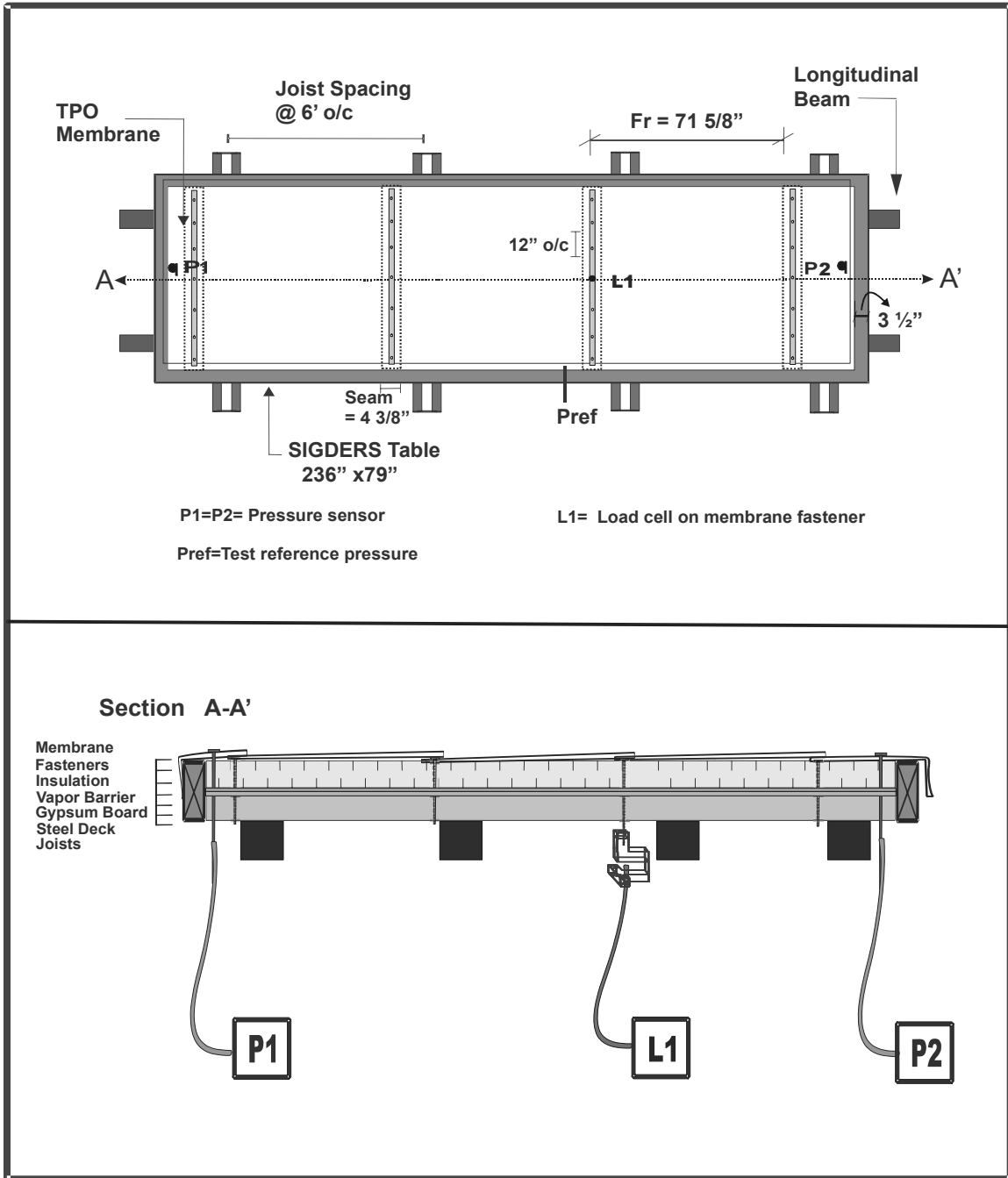
System 3 & 4 – Components Layout



System 3: 22-Ga (80/101 ksi); System 4: 20-Ga (80/107 ksi)



System 3 & 4 – Instrumentation layout



System 3 & 4- Installation



Deck Installation



Gypsum Board & Poly Installation



Insulation Attachment



Membrane Attachment

Table 4: Nominal physical and mechanical properties of the components for System 3 and System 4

Deck

Type Profiled	
Thickness*	System 3: 22 Ga (80 / 101 ksi), 0.03" (0.76 mm), nominal; 0.74 mm, measured System 4: 20 Ga (80 / 107 ksi), 0.036" (0.91 mm), nominal; 0.90 mm, measured
Overall Depth	1 1/2 " (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2004*	System 3 : 22 Ga (80 / 101 ksi) = 700 lbf (3080 N) System 4 : 20 Ga (80 / 107 ksi) = 893 lbf (3929 N)
Source Canam	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 8 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type	Vapor barrier, CGSB 51.34-M86, 6 mils poly
Type	Support Board, 4' x 8' x 1/2" gypsum board

Membrane

Type TPO,										
Width 76"										
Thickness	45 mil (1.1 mm)									
Tensile Property as per ASTM D 751-2000*	<table border="0"> <tr> <td></td> <td align="center">MD</td> <td align="center">XD</td> </tr> <tr> <td>Breaking strength, KN (lbf)</td> <td align="center">0.89 (200)</td> <td align="center">0.67 (151)</td> </tr> <tr> <td>Elongation at Max. Load, %</td> <td align="center">35</td> <td align="center">30.5</td> </tr> </table>		MD	XD	Breaking strength, KN (lbf)	0.89 (200)	0.67 (151)	Elongation at Max. Load, %	35	30.5
	MD	XD								
Breaking strength, KN (lbf)	0.89 (200)	0.67 (151)								
Elongation at Max. Load, %	35	30.5								

Attachment

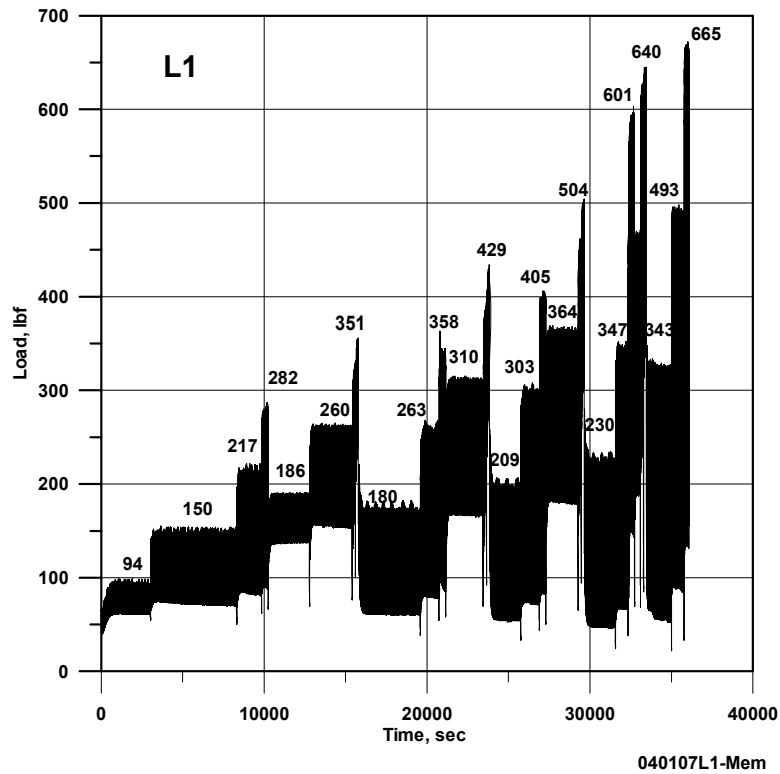
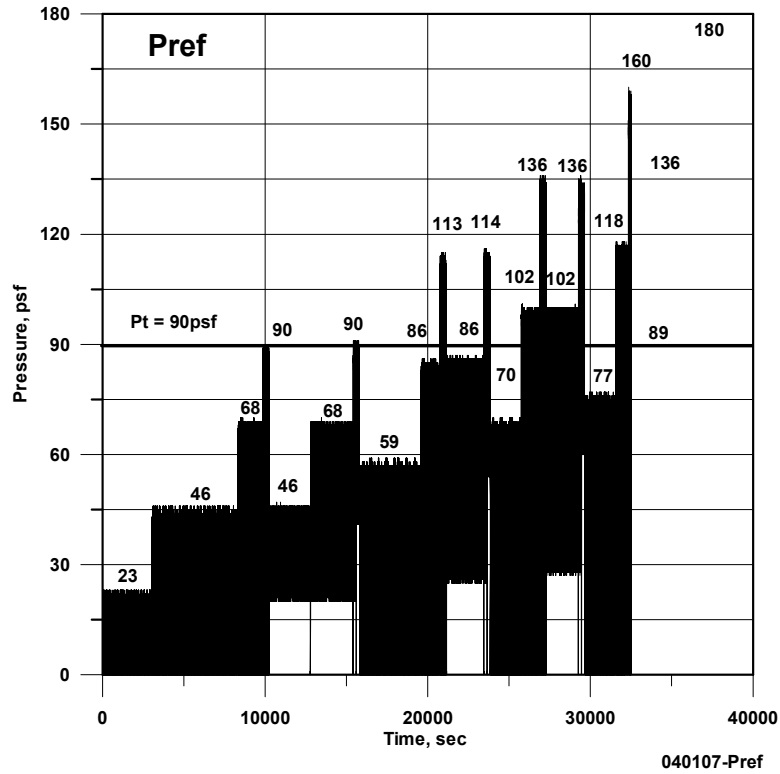
Type	Mechanical fasteners with Polymer Batten Strip
Fastener	5" (128mm), # 15
Polymer Batten	1" (25.4 mm) wide & 0.057" (1.4mm) thick
Fastener Row Spacing	71 5/8" (1791 mm)
Fastener Spacing	12" (305 mm)
Slippage Control	Yes

Seam

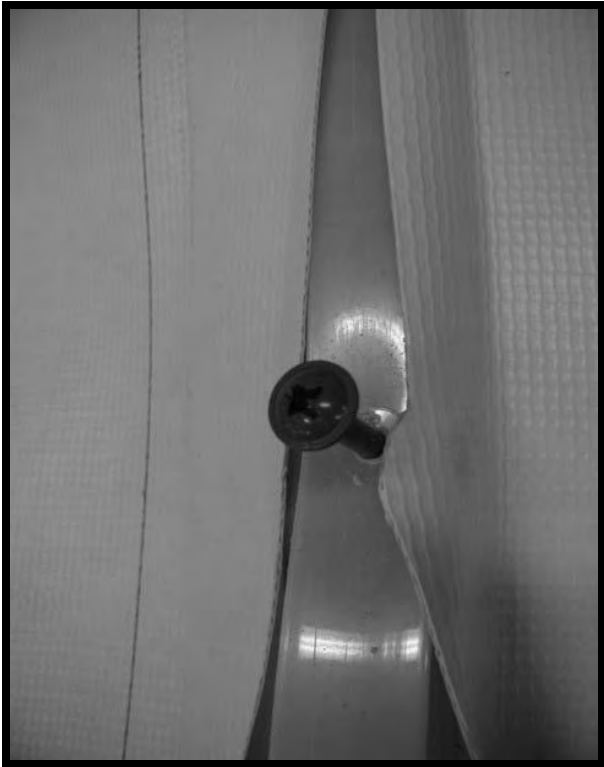
Type	Hot air welding (Double side weld)
Seaming Width	Overlap = 4 3/8" (111 mm) Temperature: 540°C Speed: 3.1m/min

* NRC Test Results

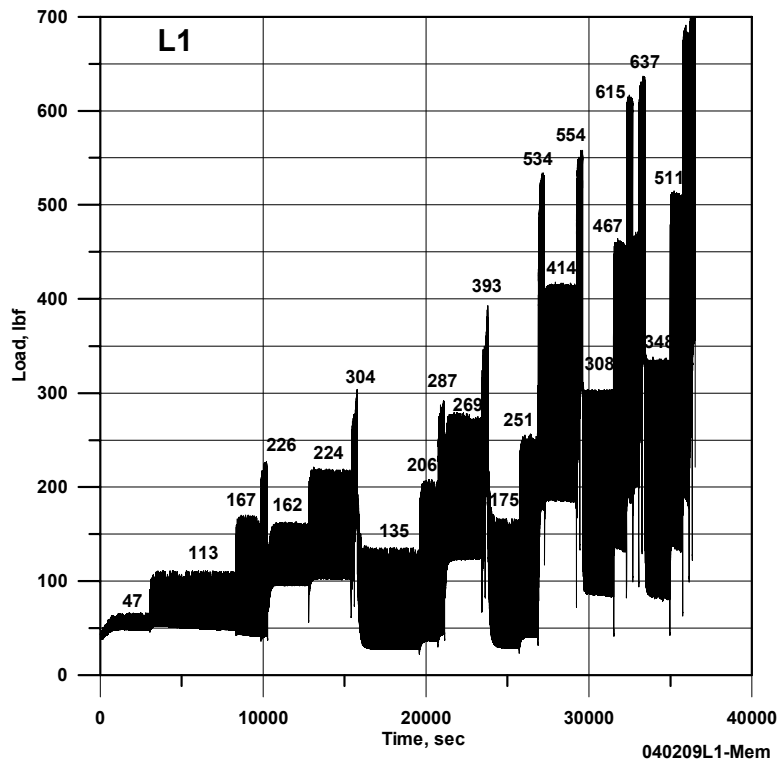
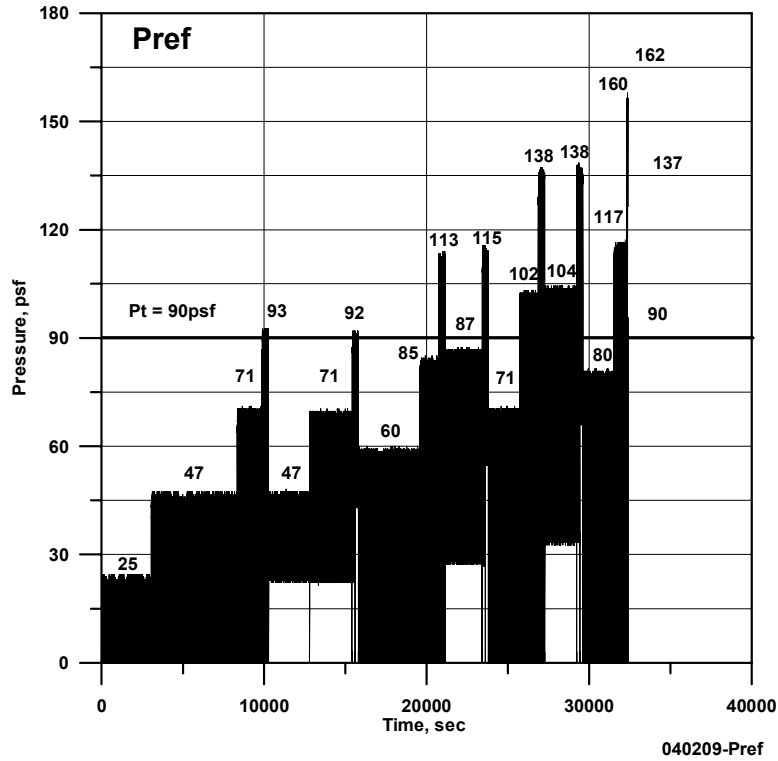
System 3 – Measured Time Histories



System 3 – Failure Mode



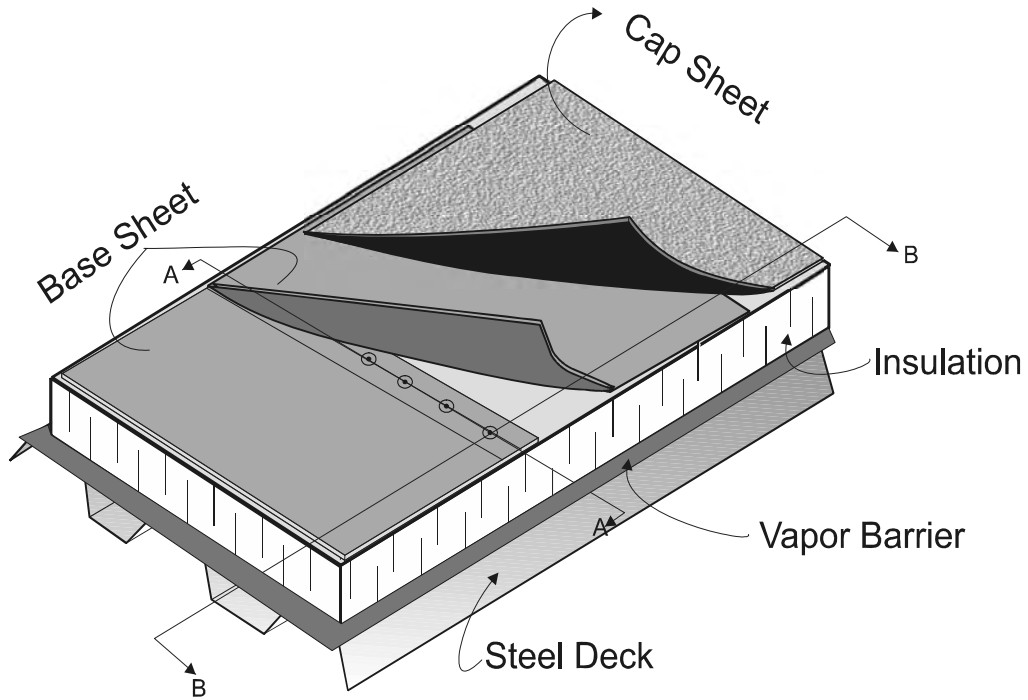
System 4 – Measured Time Histories



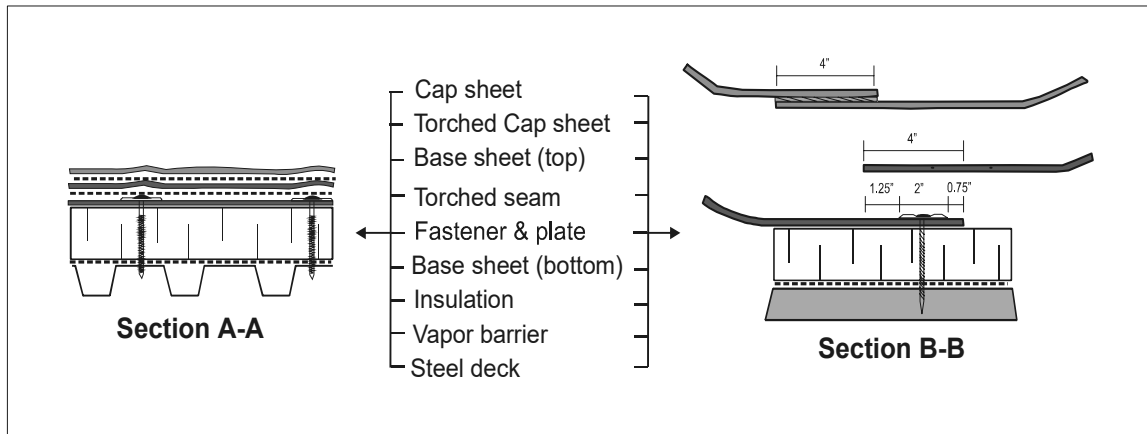
System 4 – Failure Mode



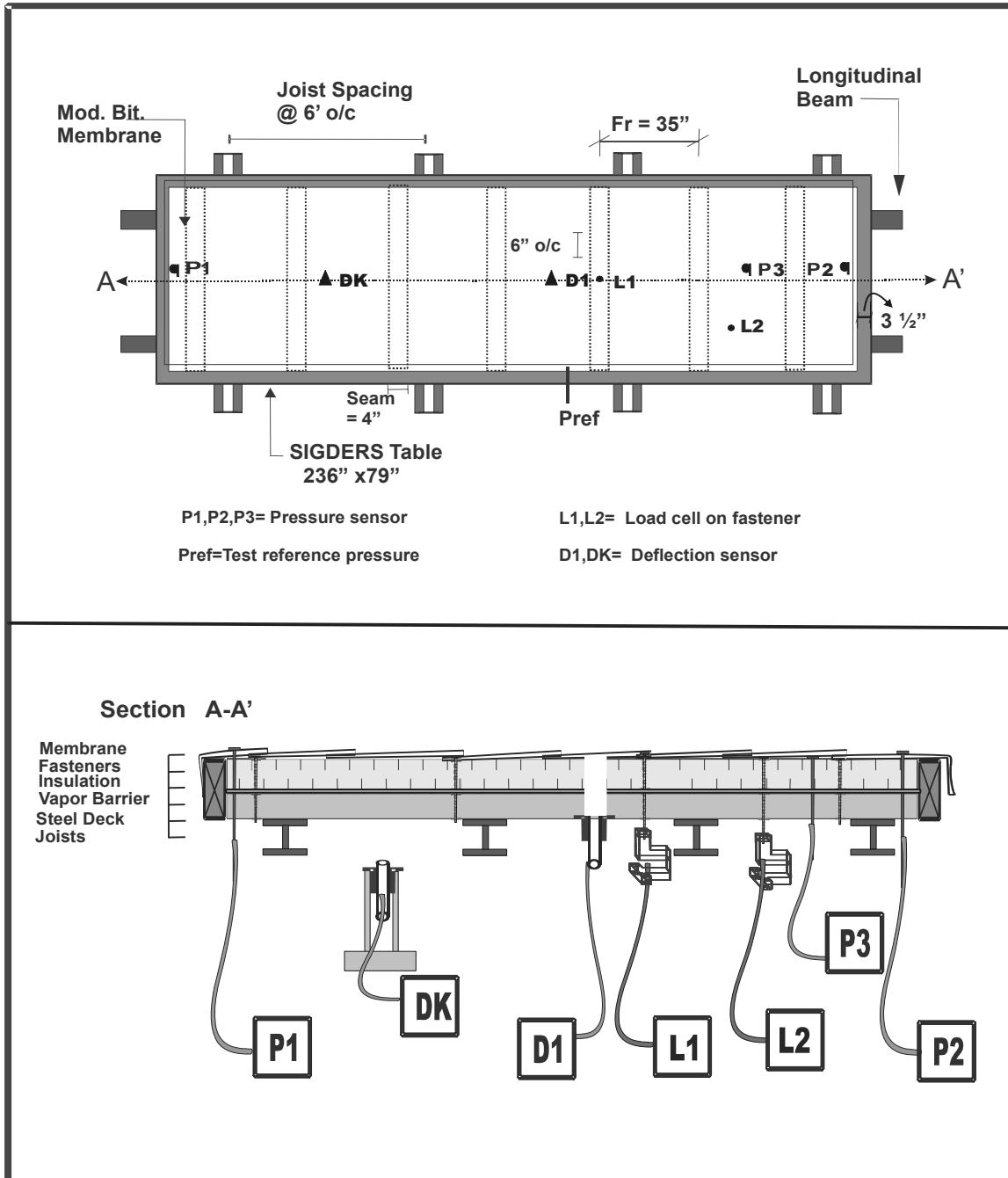
System 5 & 6 – Components Layout



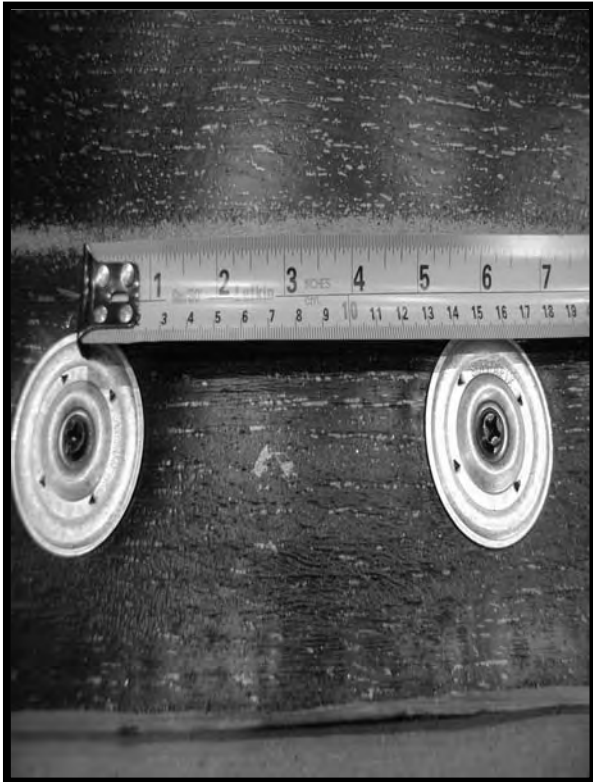
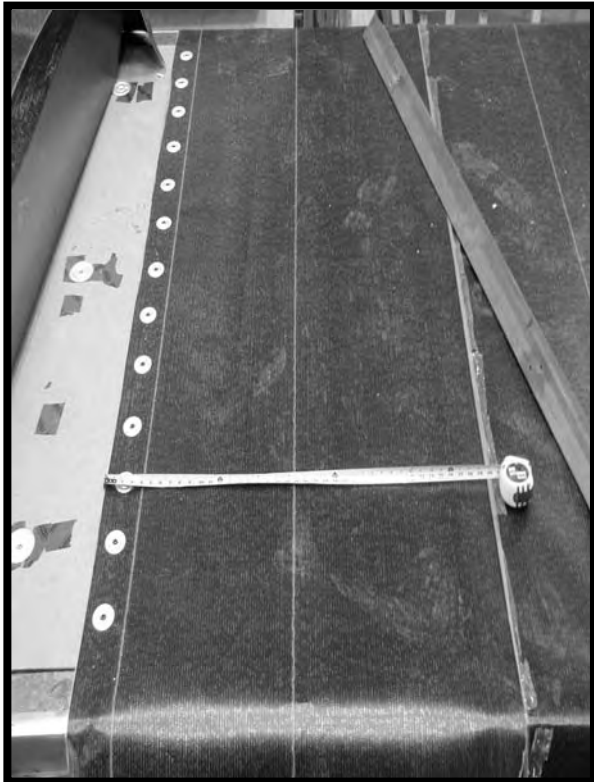
System 5: 22-Ga (33/55 ksi); System 6: 20-Ga (33/52 ksi)



System 5 & 6 – Instrumentation Layout



System 5 & 6– Installation



System 5 & 6- Installation

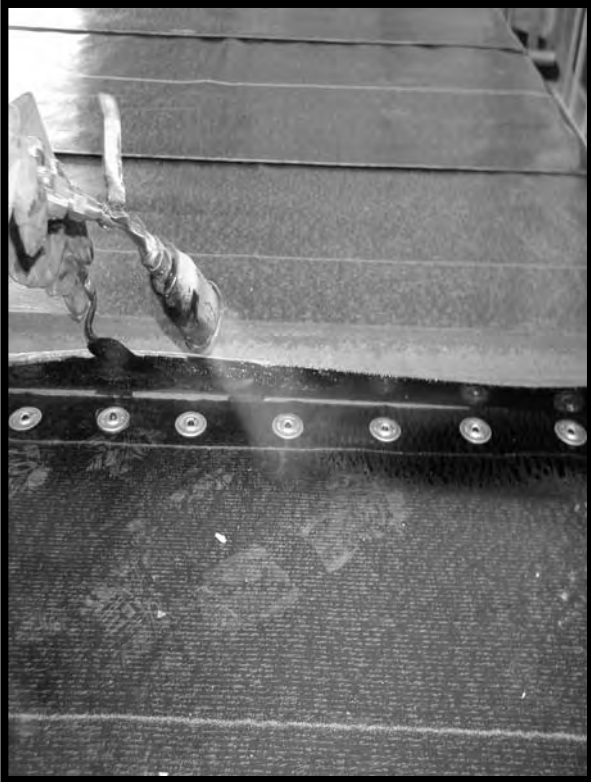


Table 5: Nominal physical and mechanical properties of the components for System 5 and System 6

Deck

Type Profiled	
Thickness*	System 5: 22 Ga (33 / 55 ksi), 0.03" (0.76 mm), nominal; 0.80 mm, measured System 6: 20 Ga (33 / 52 ksi), 0.036" (0.91 mm), nominal; 0.94 mm, measured
Overall Depth	1.5" (38 mm)
Flute Spacing	5.9" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2004*	System 5 : 22 Ga (33 / 55 ksi) = 382 lbf (1699 N) System 6 : 20 Ga (33 / 52 ksi) = 485 lbf (2157 N)
Source Canam	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 5 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type	Vapor barrier, Sopra Vapor
------	----------------------------

Membrane

Type	Mod. Bit., Base Sheet and Cap Sheet		
Width	39" (991 mm)		
Thickness	Base Sheet (2.2 mm), Cap Sheet (3.3 mm)		
Tensile Property as per CGSB-37.56-M-97, 23°C* (Base Sheet)	Max. Load (N/mm)	MD 15.4	XD 13.7
	Elongation at Max Load (%)	62	58
	Strain energy (KN/mm)	7.3	6.5
Tensile Property as per CGSB-37.56-M-97, 23°C* (Cap Sheet)	Max. Load (N/mm)	15.6	13.9
	Elongation at Max Load (%)	55	59
	Strain energy (KN/mm)	6.9	6.6

Attachment

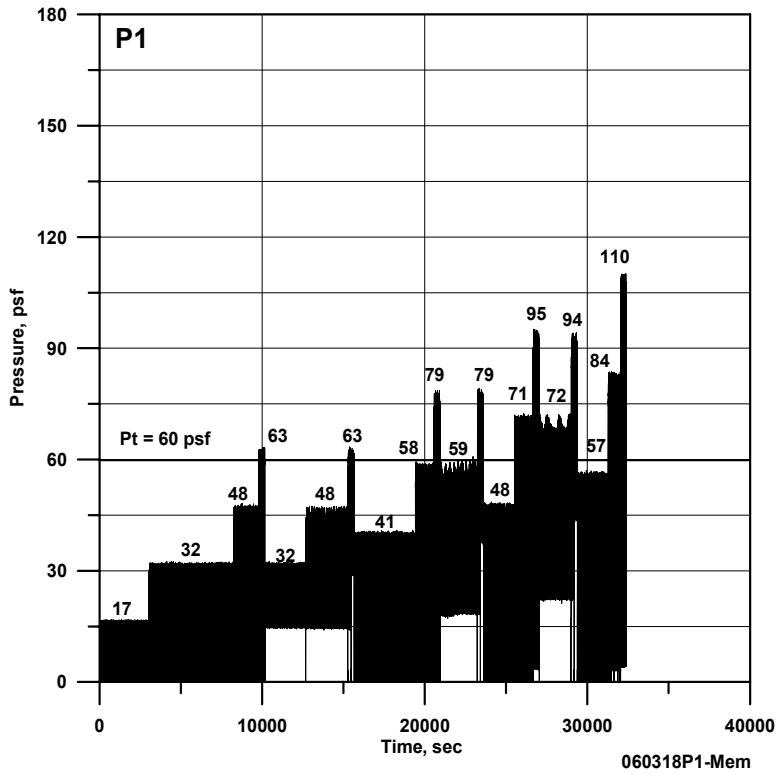
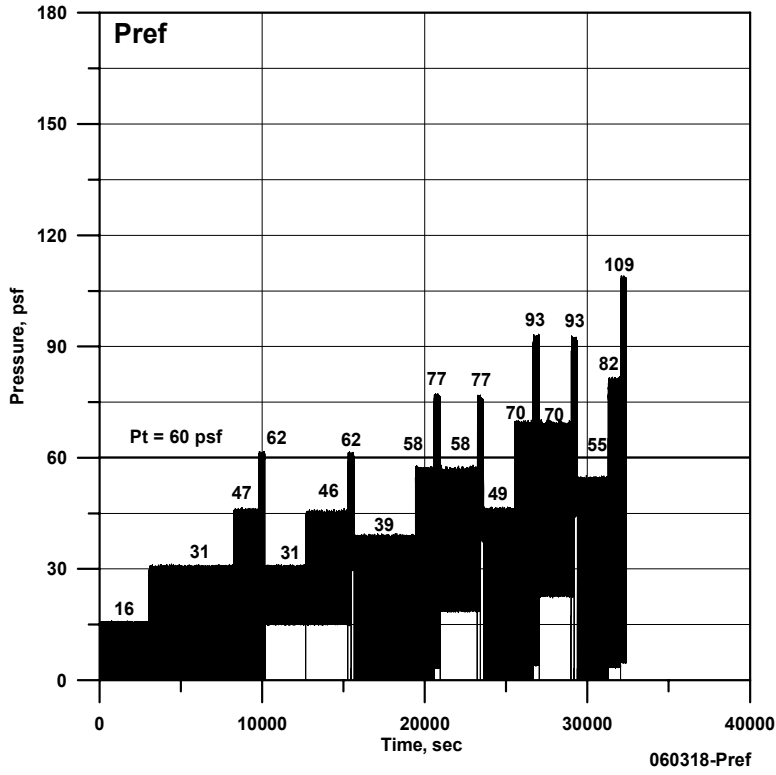
Type	Mechanical fasteners with Plates
Fastener	3" (76mm), # 14
Fastener Plate	2" (51 mm) dia. Metal Plate
Fastener Row Spacing	35" (889 mm)
Fastener Spacing	6" (152 mm)

Seam

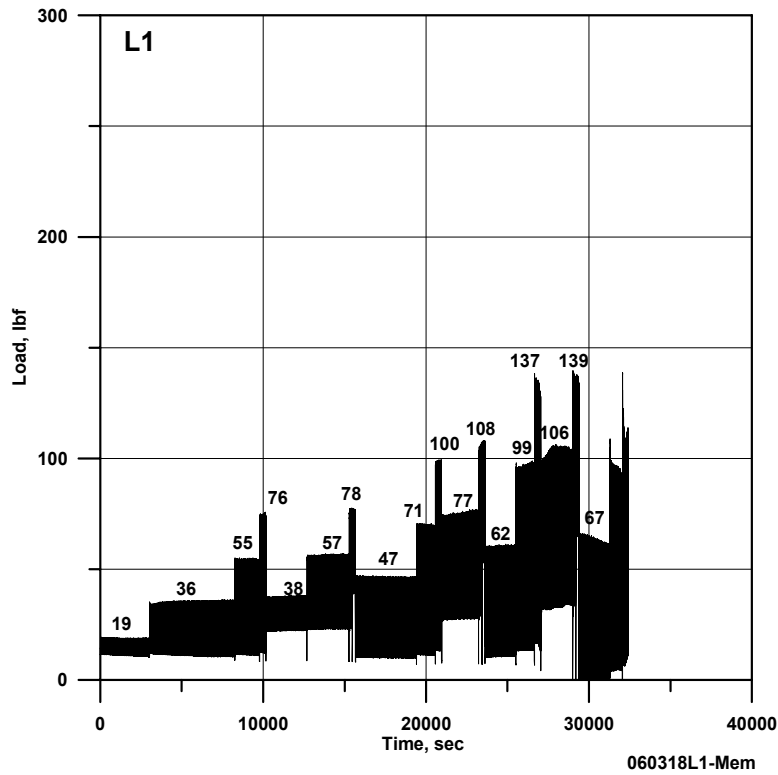
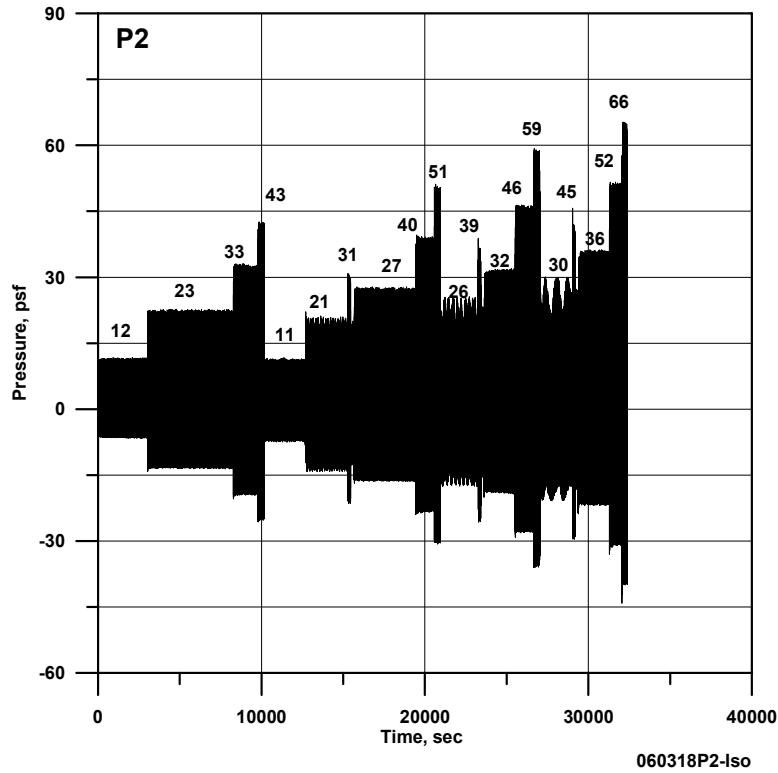
Type Torching	
Seaming Width	Overlap = 4" (102 mm)

* NRC Test Results

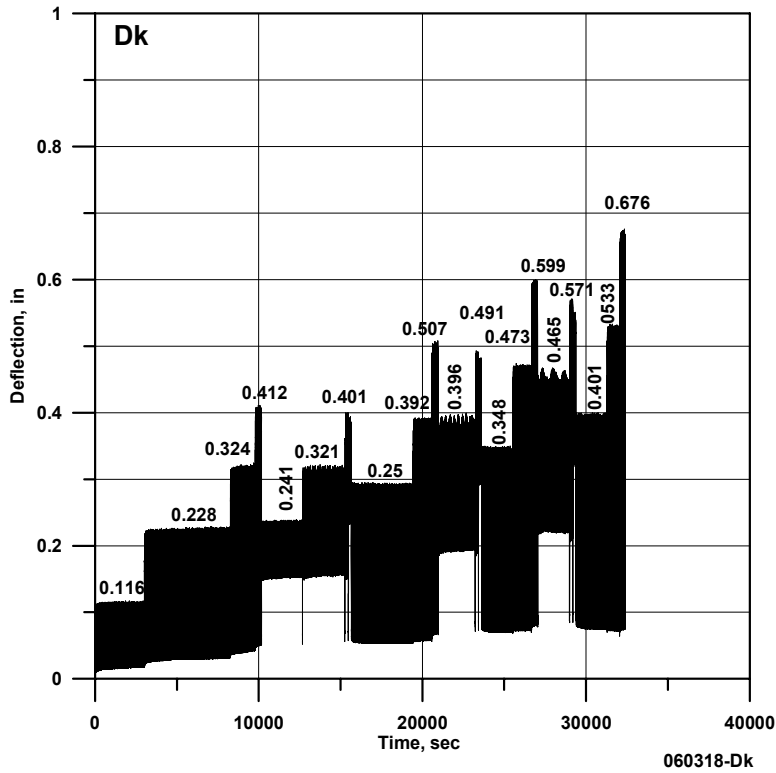
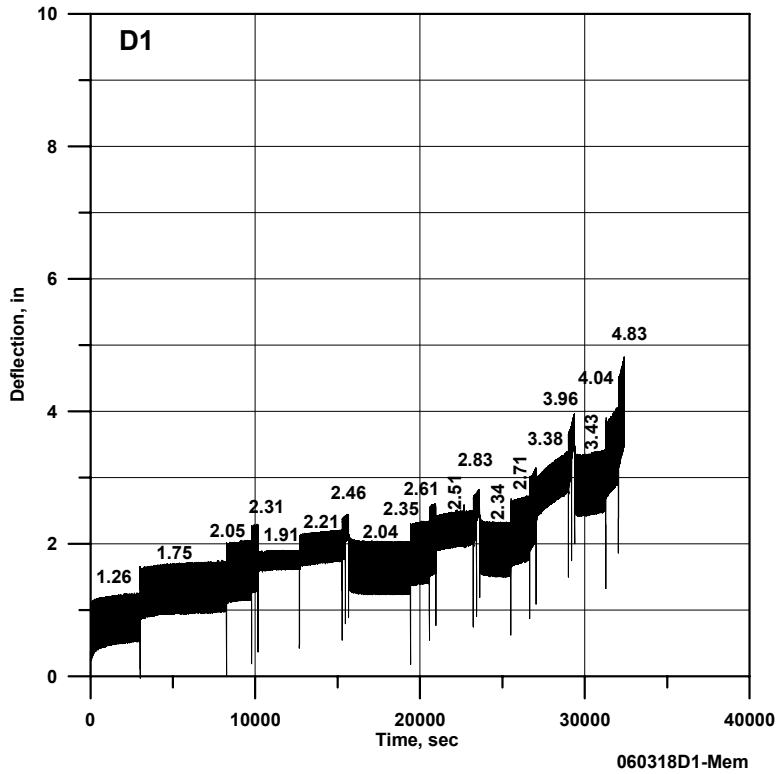
System 5 – Measured Time Histories



System 5 – Measured Time Histories



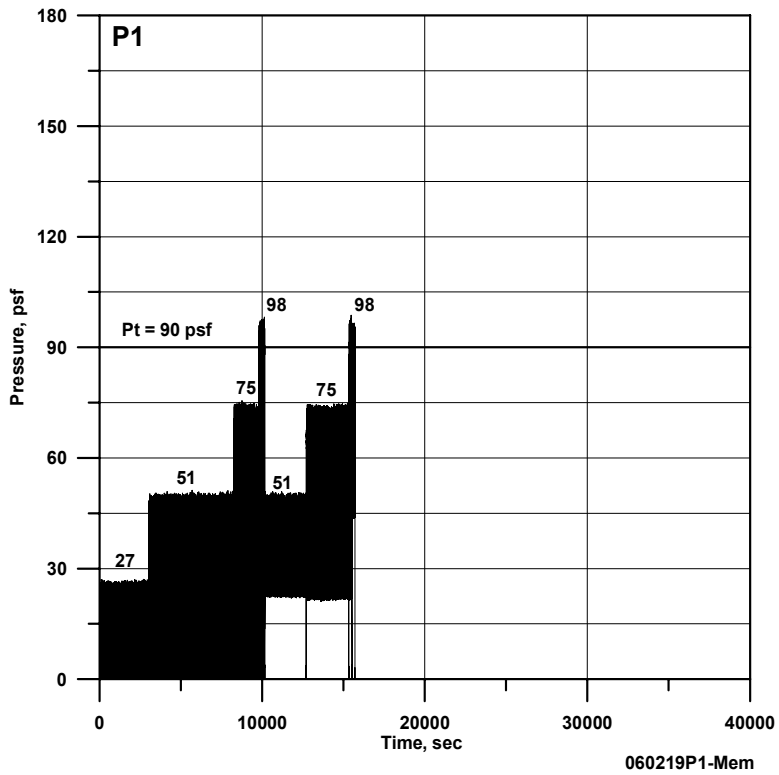
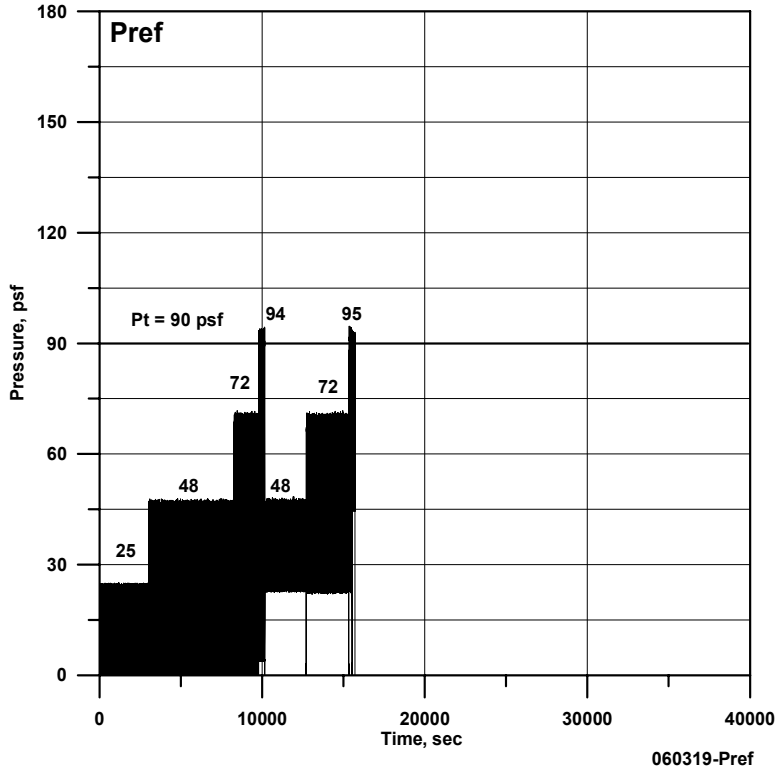
System 5 – Measured Time Histories



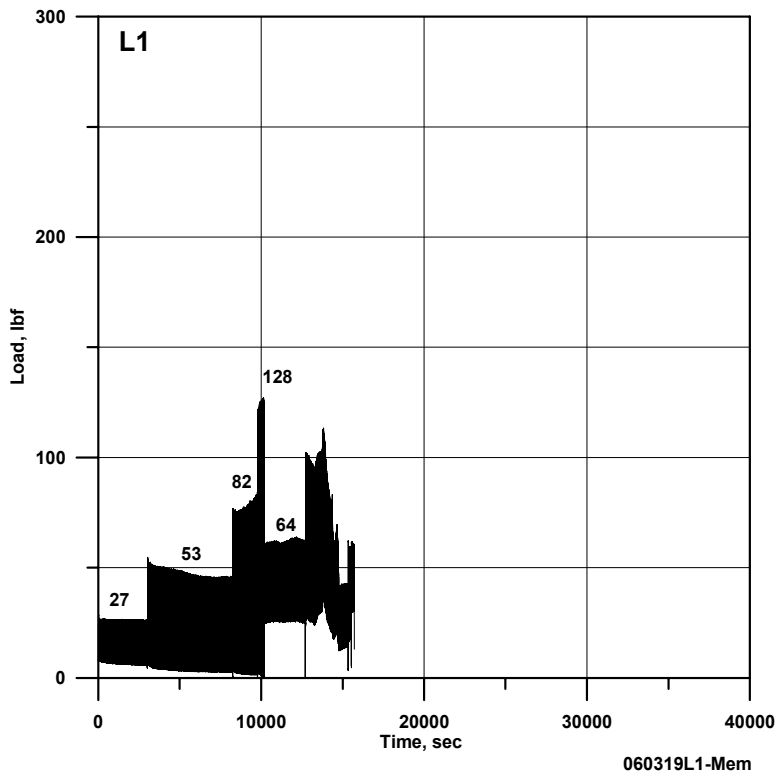
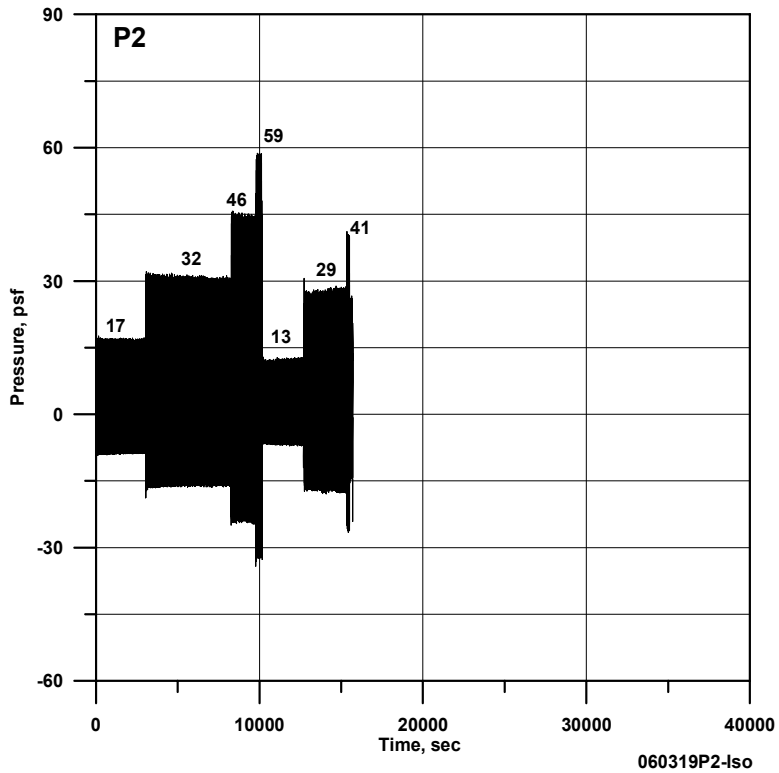
System 5 – Failure Mode



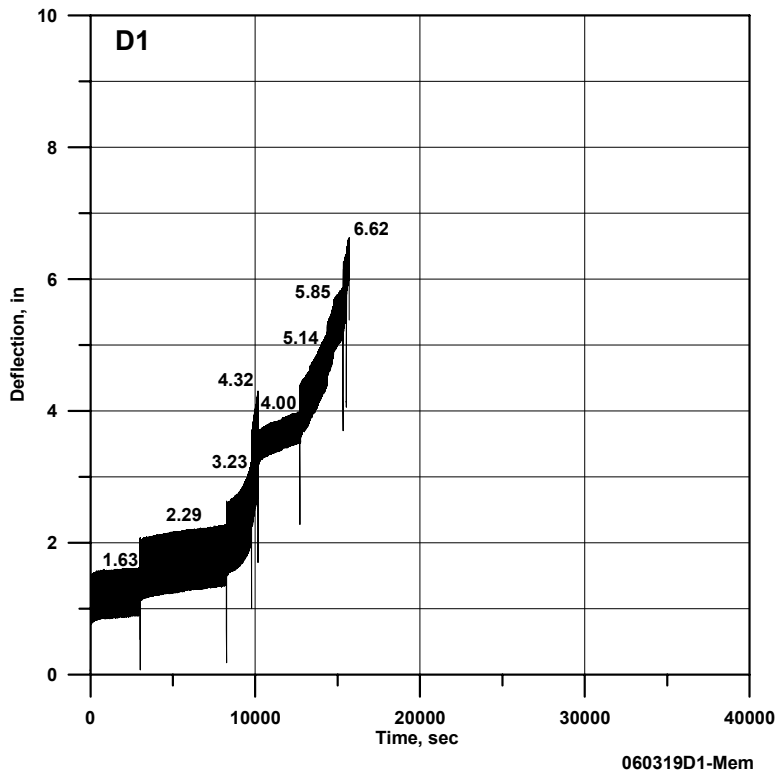
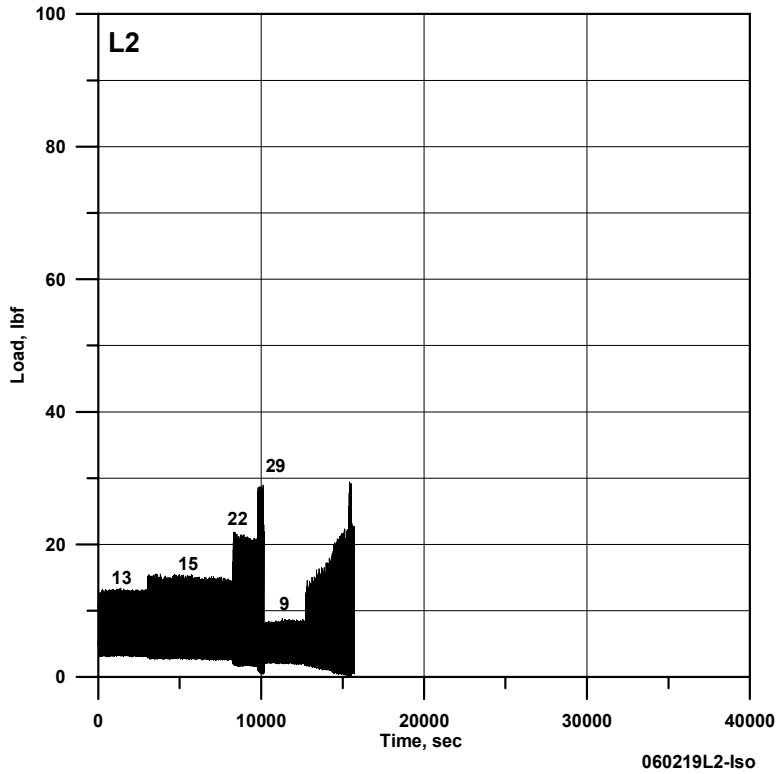
System 6 – Measured Time Histories



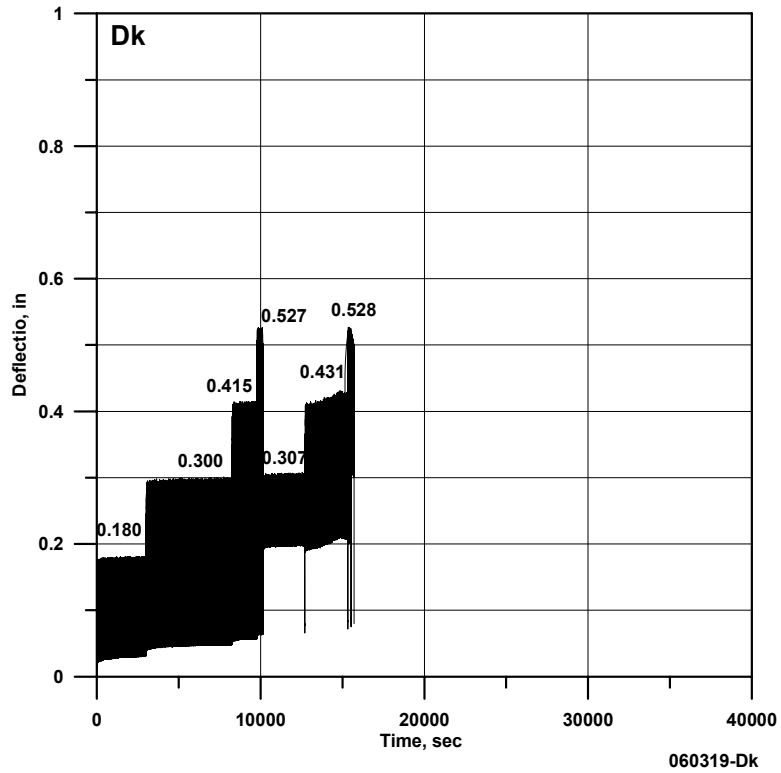
System 6 – Measured Time Histories



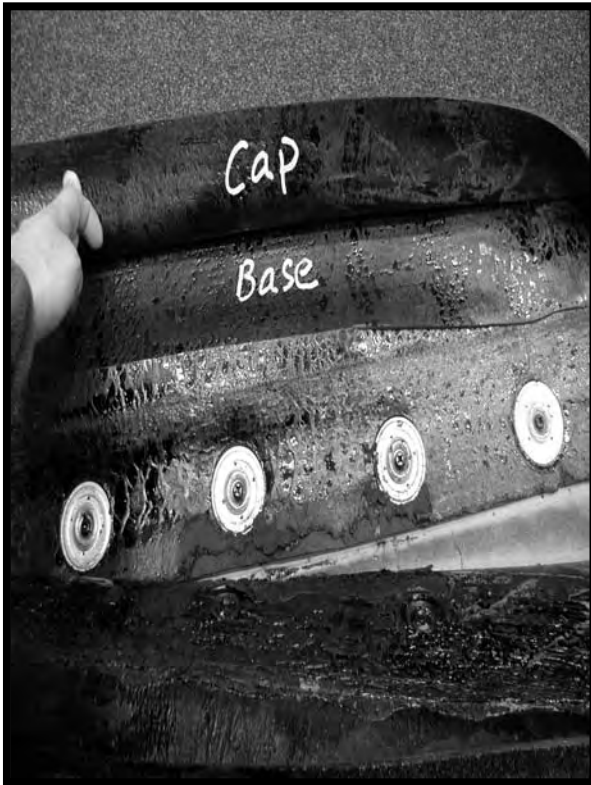
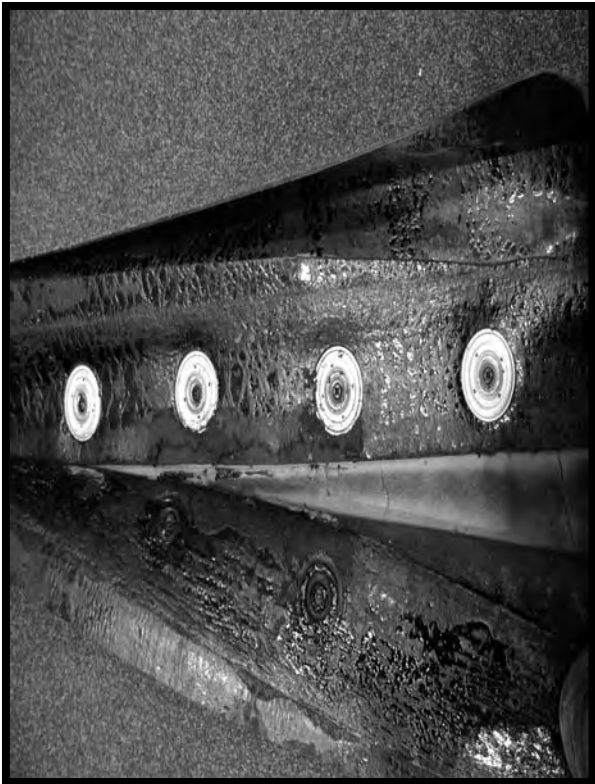
System 6 – Measured Time Histories



System 6 – Measured Time Histories



System 6 – Failure Mode



PART – B

Wind Uplift Resistance Data - Influence of Deck Span and Membrane Seam Fastened Parallel and Perpendicular to Deck Flute

Table 6: Wind Uplift Resistance Data - Influence of Deck Span and Membrane Seam Fastened Parallel and Perpendicular to Deck Flute (Imperial Units)

System	Sustained Pressure (psf)	Sustained Load (lbf)	Membrane / Deck Deflection (in)	Failure Mode
System 7 (060215) Pt=60psf 22 Ga *(33/55 ksi), 6' joist span, PVC 1, Double Sided Weld, Polymer Batten Strip, #15 Fastener	75	417 / 521**	8.4 / 0.401	Membrane fastener pullout
System 8 (060217) Pt=60psf Same as the system 7 with 4' joist span	90	497 / 521**	9.2 / 0.385	Cracking of batten bar and membrane fastener pulled through
System 9 (051233) Pt=90psf 22 Ga *(33/55 ksi), PVC 2 – 38", Fr/Fs = 32 3/4" / 6", One Sided Weld, 2 3/8" round plate, and #15 Fastener	113	226 / 530**	5.92 / 0.7	Membrane seam delamination
System 10 (060322) Pt=90psf Same as system 9 with membrane fastened parallel to the steel deck flute	Failed at Seq. 7, Level A	N/A	N/A	Steel deck cracked and deck fasteners pulled through the deck
System 11 (060320) Pt=60psf 20 Ga *(80/107 ksi), Mod. Bit. Sopra Vapor as Barrier, base sheet attached at 6" o/c with metal plate, #14 Fastener and Cap sheet torched.	120	178 / 651**	3.78 / 0.62	Passed P ¹²⁰ - No failure observed
System 12 (060321) Pt=60psf Same as the System 11 with 20 Ga *(80/107 ksi) steel deck and base sheet fastened parallel to the steel deck flute	105	135 / 651**	3.36 / 0.781	Steel deck cracked and deck fastener pulled through the deck

* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

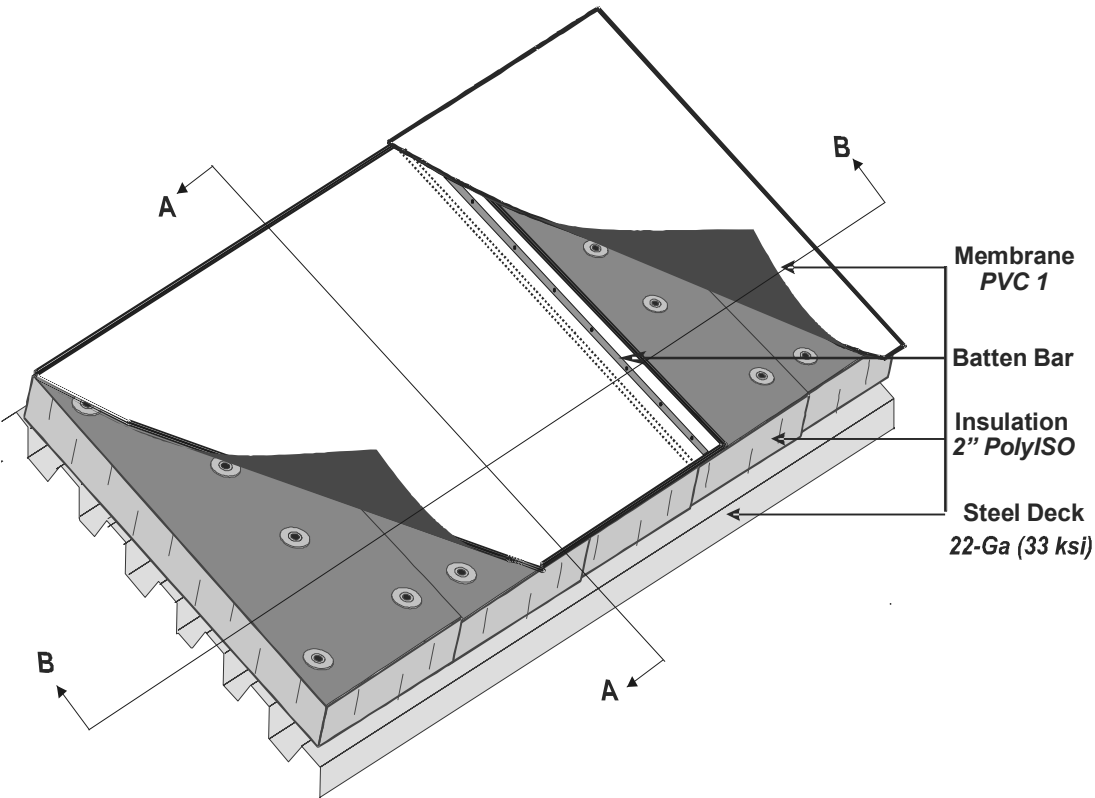
Table 7: Wind Uplift Resistance Data - Influence of Deck Span and Membrane Seam Fastened Parallel and Perpendicular to Deck Flute (SI Units)

System	Sustained Pressure (Pa)	Sustained Load (N)	Membrane / Deck Deflection (mm)	Failure Mode
System 7 (060215) Pt=2873Pa 22 Ga *(230/380 Mpa), PVC 1 – 1930mm, Fr/Fs = 1797/305 mm, Double Sided Weld, Polymer Batten Strip, #15 Fastener and with 1.83 m joist span	3591	1835 / 2292 **	213.36 / 10.19	Membrane fastener pullout
System 8 (060217) Pt=2873Pa Same as the system 9 with 1.22 m joist span	4309	2187 / 2292**	233.68 / 9.78	Cracking of batten bar and membrane fastener pulled through
System 9 (051233) Pt=4309Pa 22 Ga *(230/380 Mpa), PVC 2 – 965 mm, Fr/Fs = 832/152 mm, One Sided Weld, 60 mm round plate, and #15 Fastener	5410	994 / 2332**	150.37 / 17.78	Membrane seam delamination
System 10 (060322) Pt=4309Pa Same as system 9 with membrane fastened to parallel to the steel deck flute	Failed at Seq. 6, Level A	N/A	N/A	Steel deck cracked and deck fasteners pulled through the deck
System 11 (060320) Pt=2873Pa 22 Ga *(550/740 Mpa), Mod. Bit. Sopra Vapor as Barrier, base sheet attached at 152 mm o/c with metal Plate, #14 Fastener and Cap sheet torched.	5745	783 / 2864**	96.01 / 15.75	Passed P ₁₂₀ - No failure observed
System 12 (060321) Pt=2873Pa Same as the System 5 with 20 Ga *(550/740 Mpa) steel deck and base sheet fastened parallel to the steel deck flute	5027	594 / 2864**	85.34 / 19.84	Steel deck cracked and deck fastener pulled through the deck

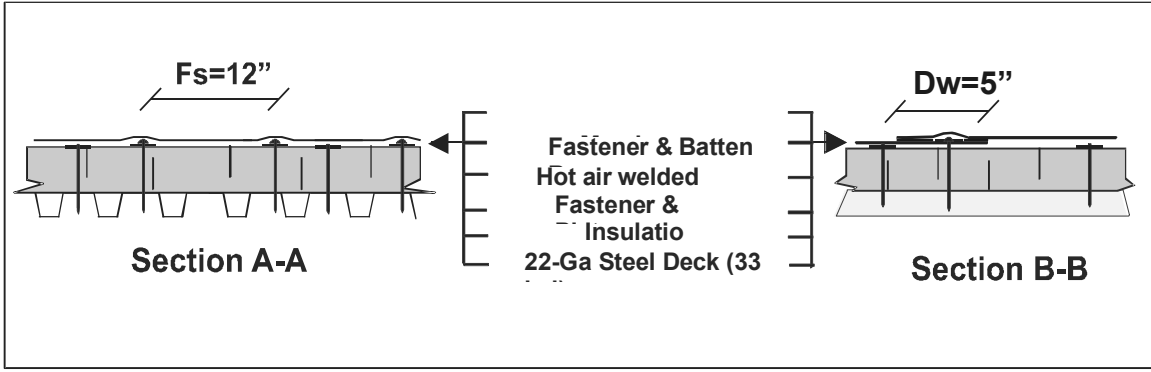
* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

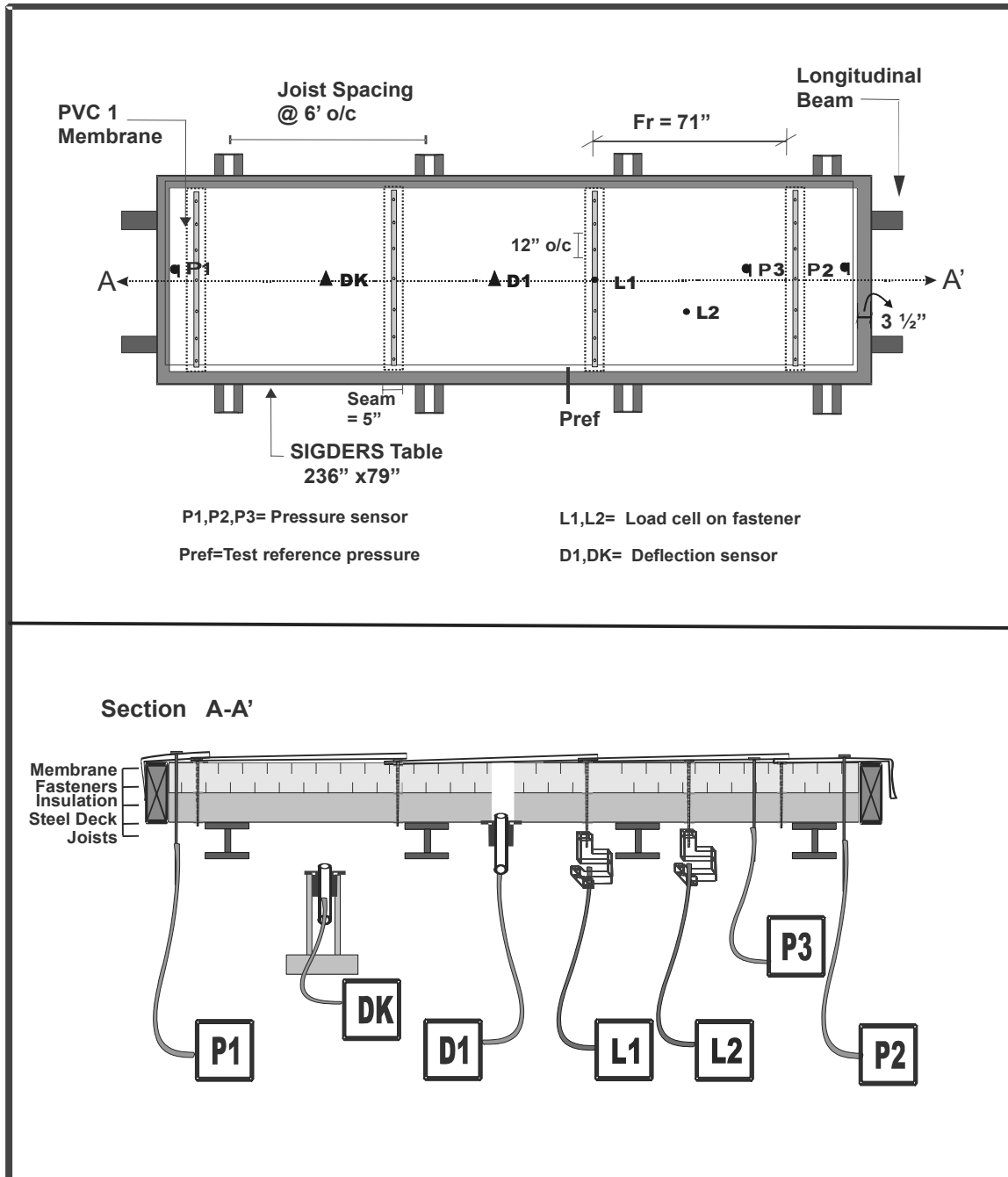
System 7 & 8- Components Layout



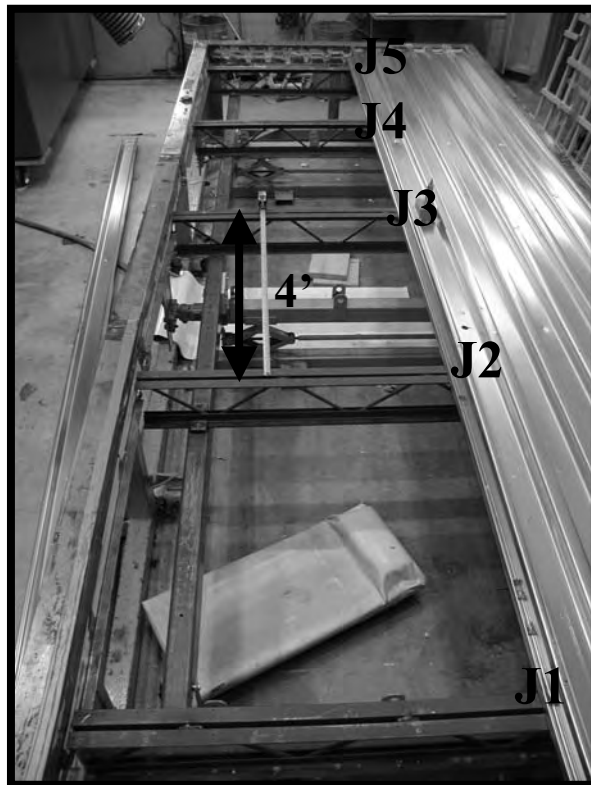
System 7: 6' Joist Spacing; System 8: 4' Joist Spacing



System 7 & 8 – Instrumentation Layout



System 7 & 8- Installation



System 7 & 8 Installation

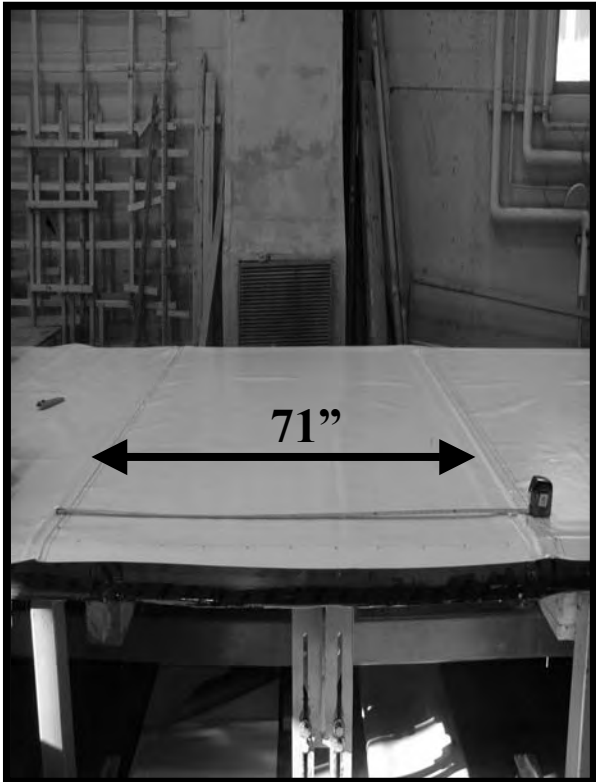
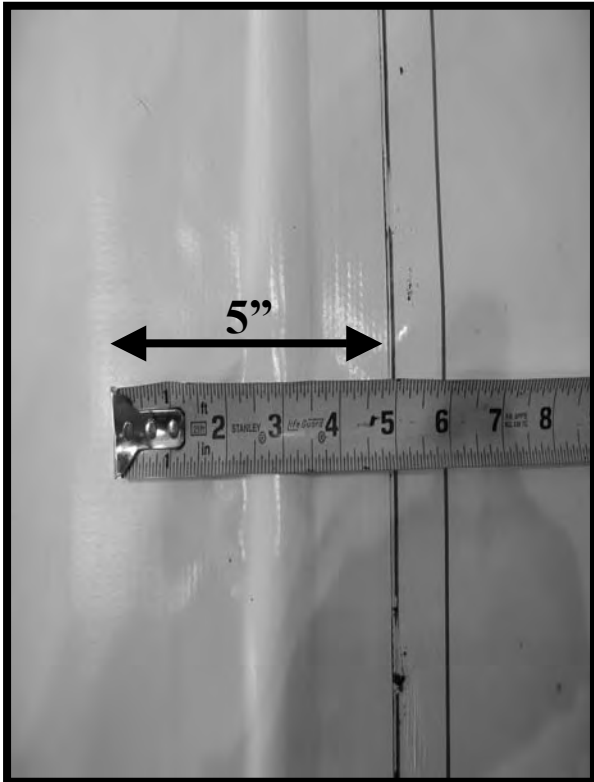
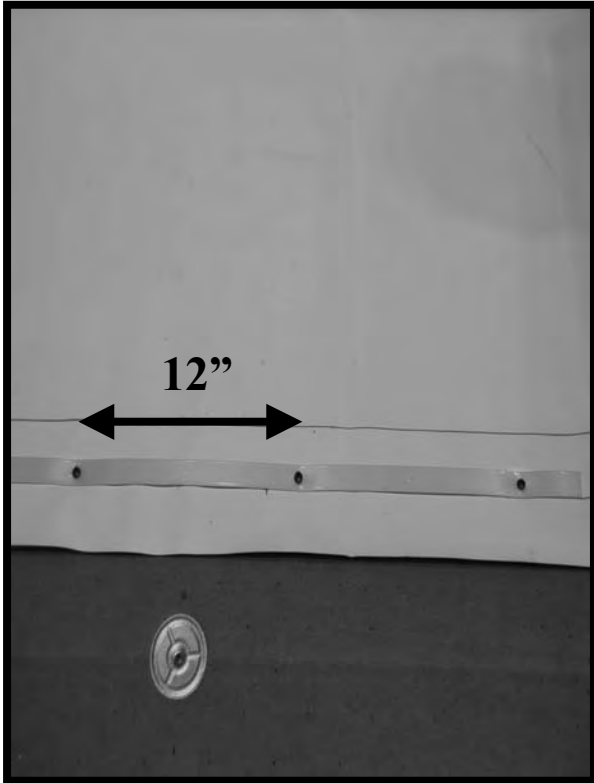


Table 8: Nominal physical and mechanical properties of the components for System 7 and System 8

Deck

Type	Profiled 22 gauge metal
Thickness*	22 Ga: 0.03" (0.76 mm), nominal; 0.80 mm, measured
Overall Depth	1 1/2" (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2006*	22 Ga (33 / 55 ksi) = 521lbf (2292N)
Source Vicwest	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 8 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type None	
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Membrane

Type PVC										
Width	76" (1930 mm)									
Thickness	45 mil (1.1 mm)									
Tensile Property as per ASTM D 751-2000*	<table border="0" style="width: 100%;"> <tr> <td></td> <td align="center">MD</td> <td align="center">XD</td> </tr> <tr> <td>Breaking strength, KN (lbf)</td> <td align="center">1.46 (327)</td> <td align="center">1.28 (288)</td> </tr> <tr> <td>Elongation at Max. Load, %</td> <td align="center">29.2</td> <td align="center">25</td> </tr> </table>		MD	XD	Breaking strength, KN (lbf)	1.46 (327)	1.28 (288)	Elongation at Max. Load, %	29.2	25
	MD	XD								
Breaking strength, KN (lbf)	1.46 (327)	1.28 (288)								
Elongation at Max. Load, %	29.2	25								

Attachment

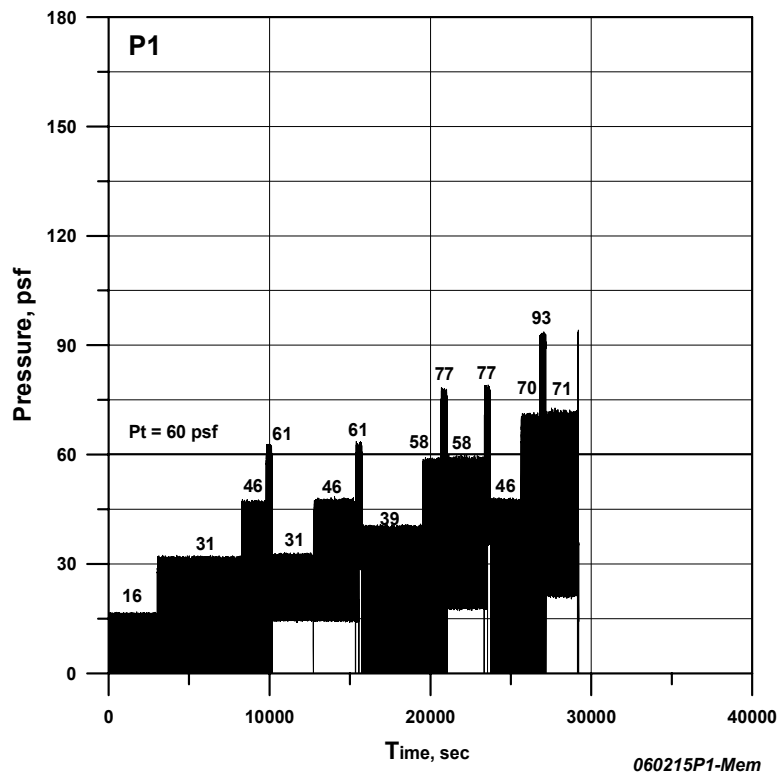
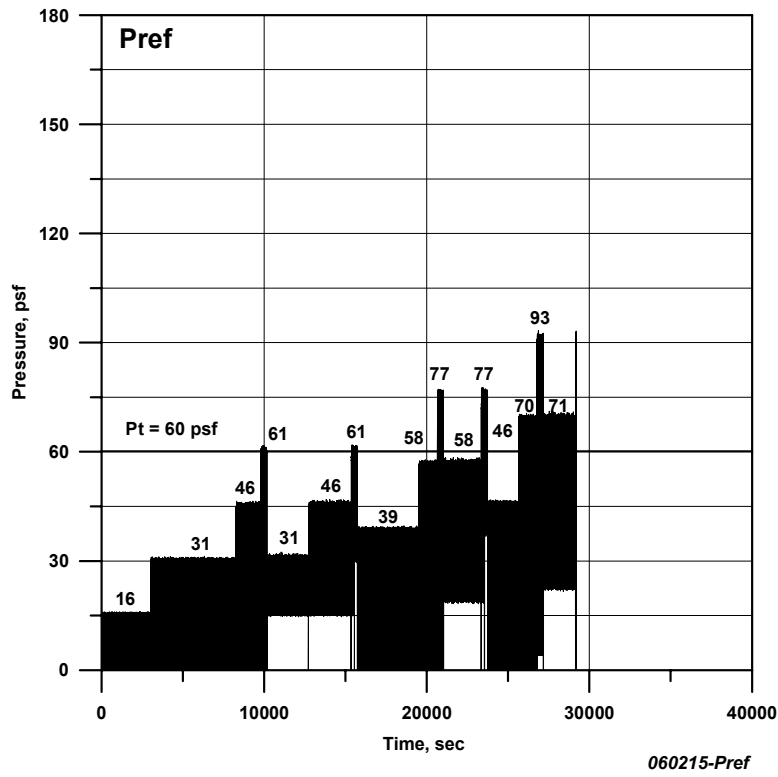
Type	Mechanical fasteners with batten bar
Fastener	5" (127mm), #15
Polymer Batten Bar	1" (25.4 mm) wide & 0.057" (1.4mm) thick
Fastener Row Spacing	71" (1803 mm)
Fastener Spacing	12" (305 mm)
Slippage Control	Yes

Seam

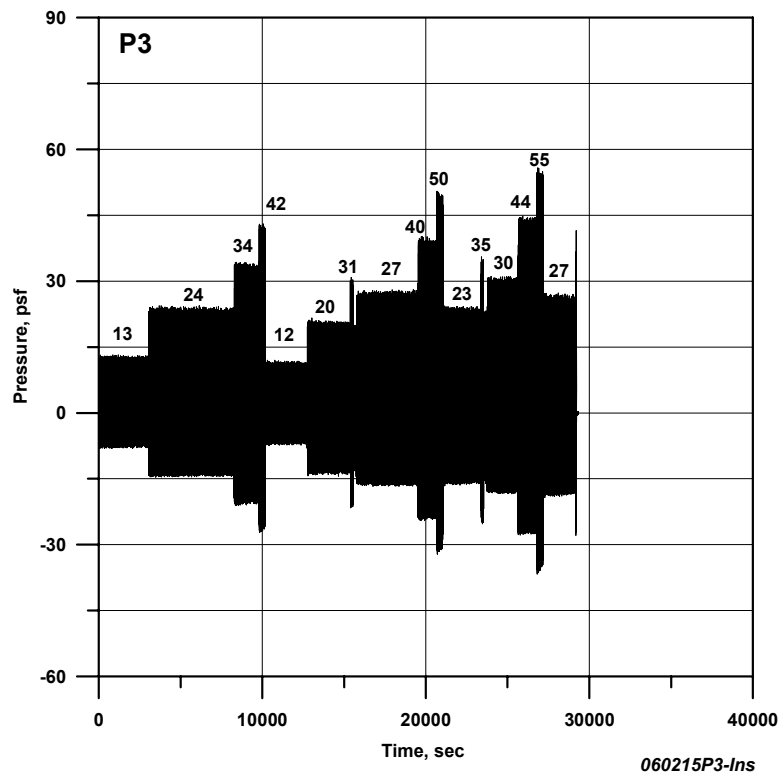
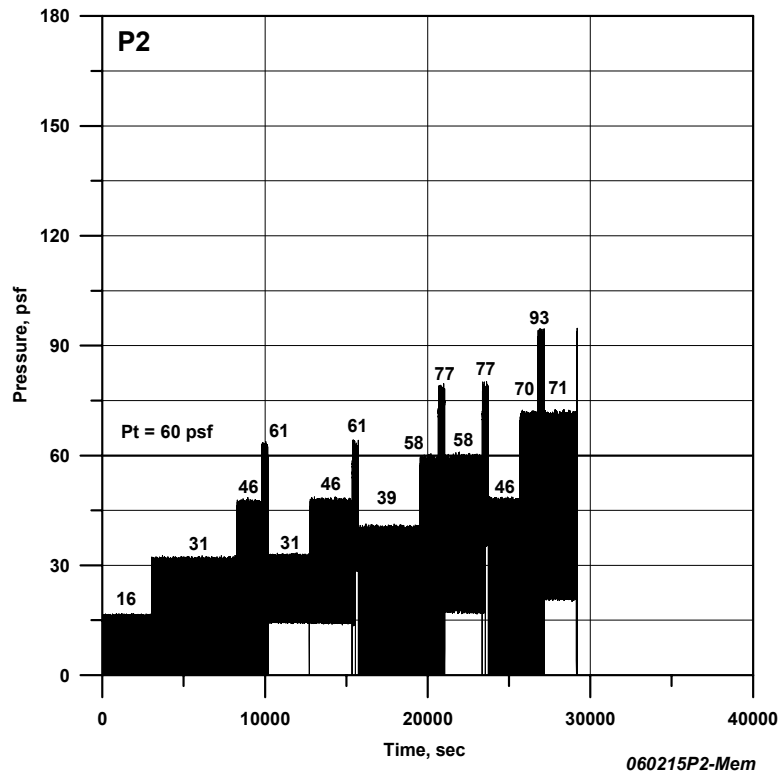
Type	Hot air welding (Double side weld)
Seaming Width	Overlap = 5" (127 mm) Temperature: 560°C Speed: 1.7m/min

* NRC Test Results

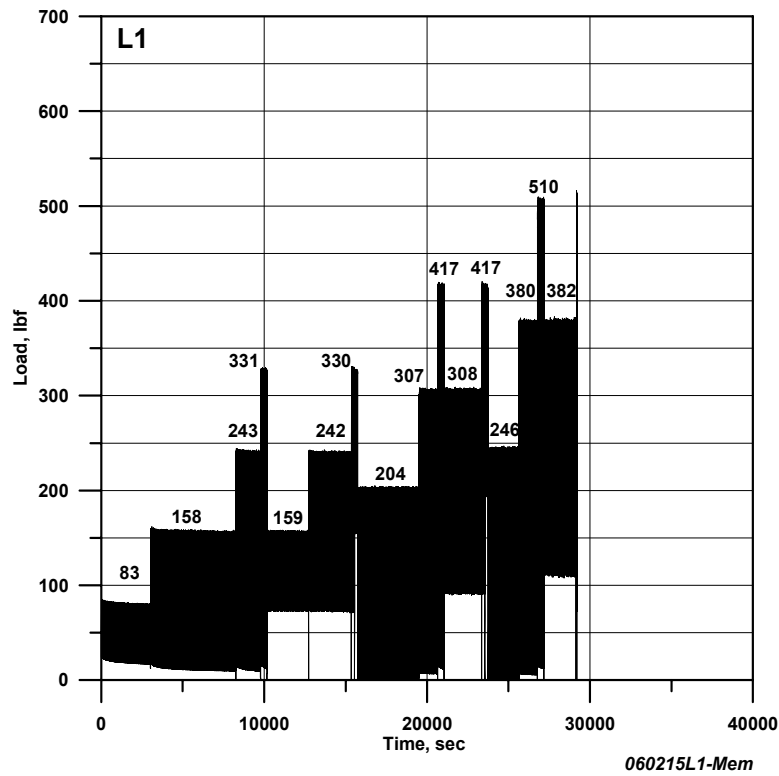
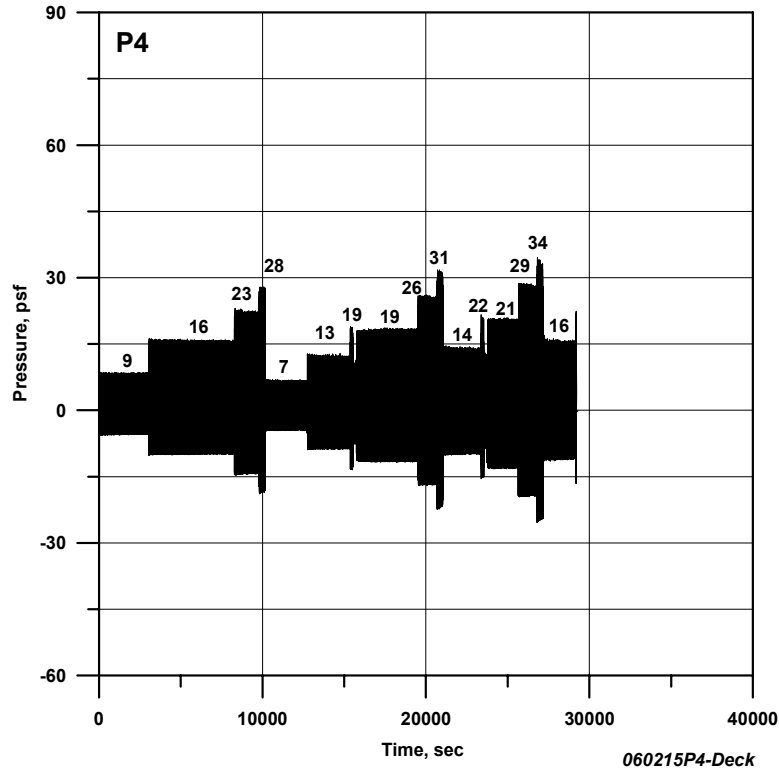
System 7- Measured Time Histories



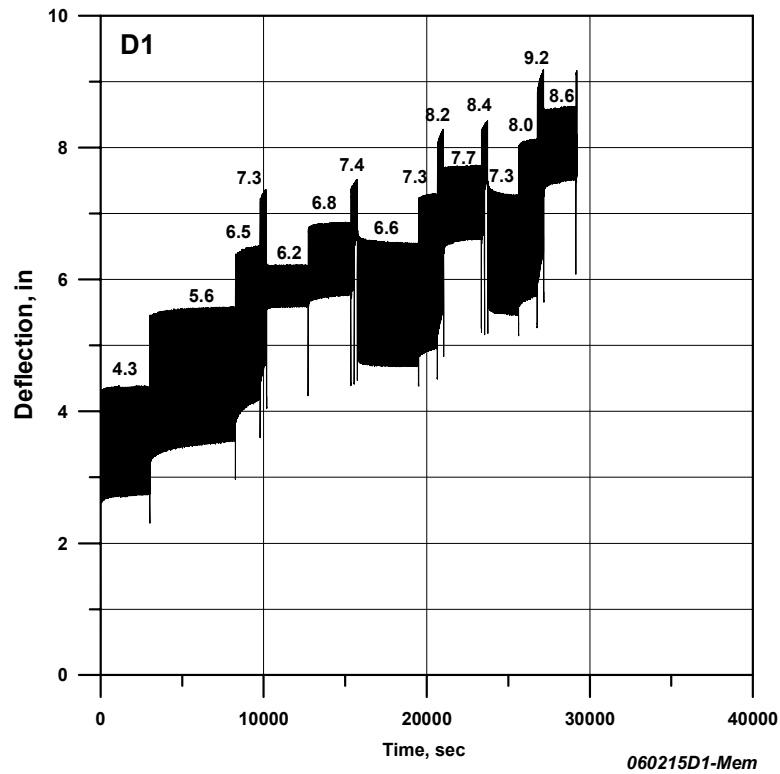
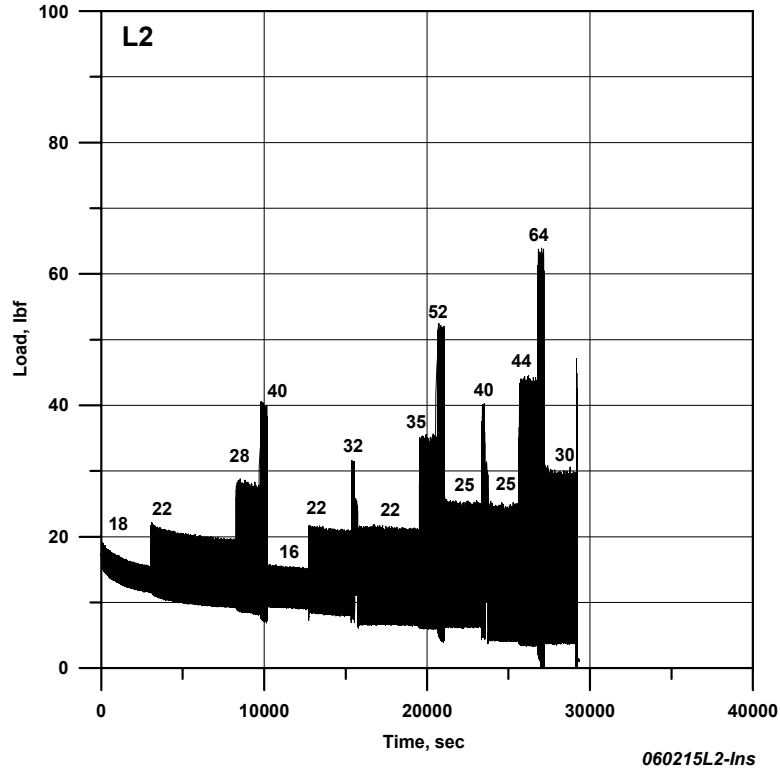
System 7- Measured Time Histories



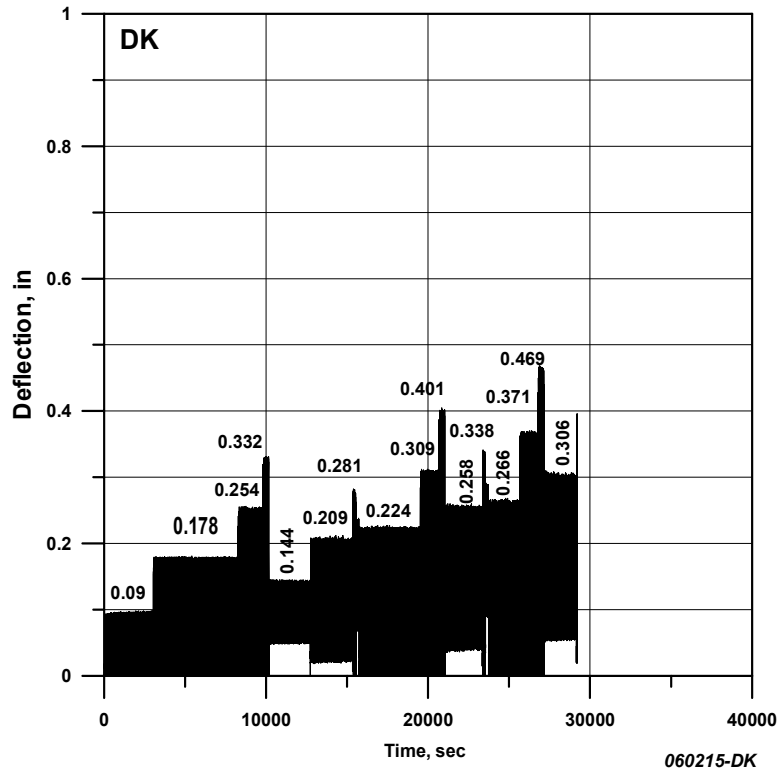
System 7- Measured Time Histories



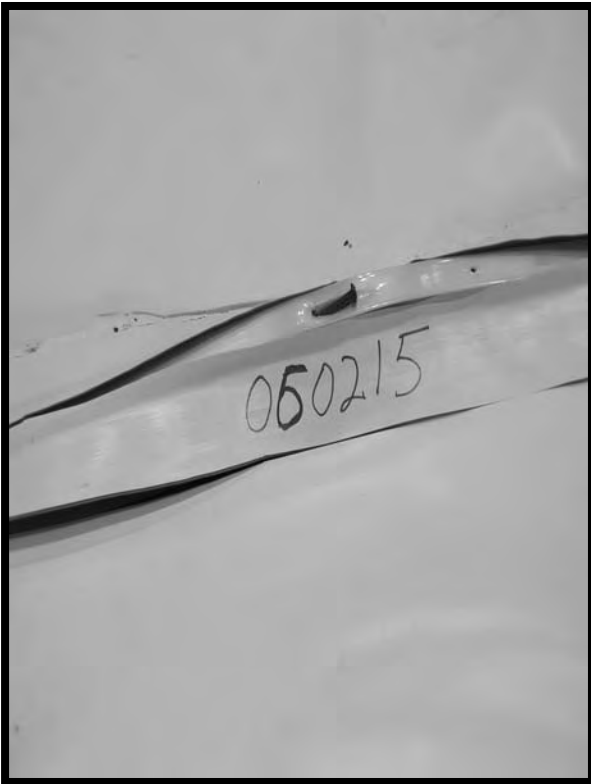
System 7- Measured Time Histories



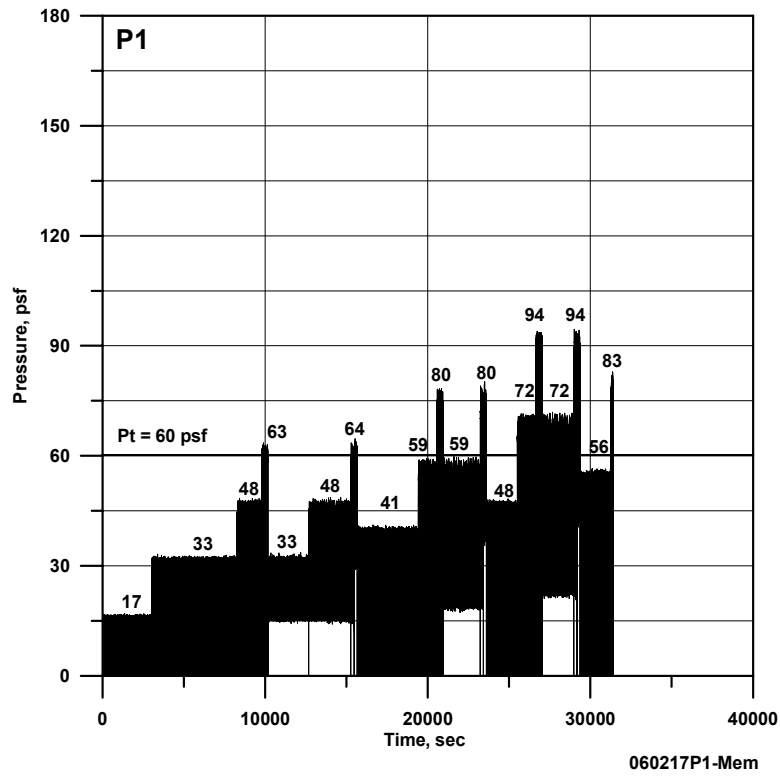
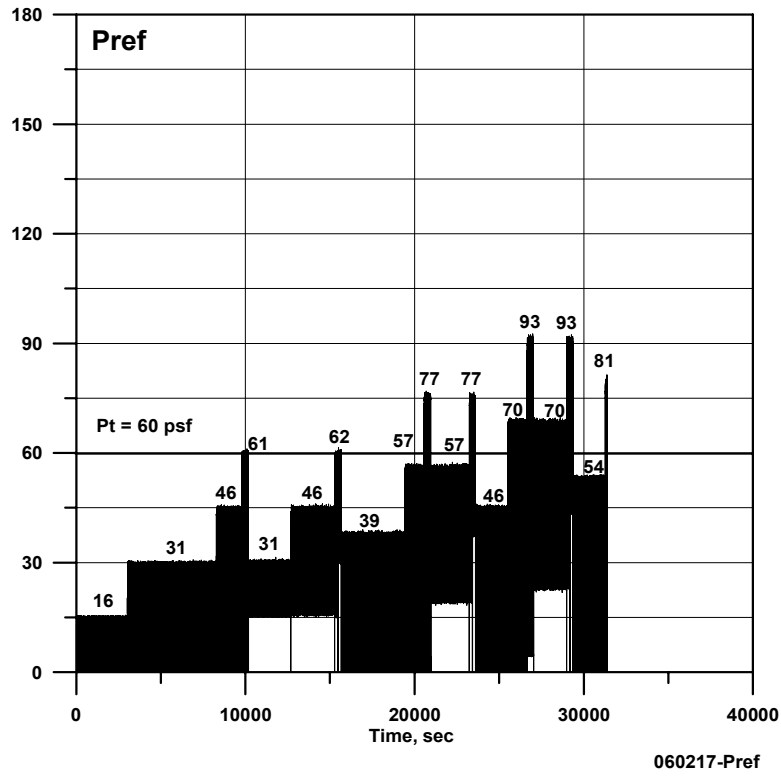
System 7- Measured Time Histories



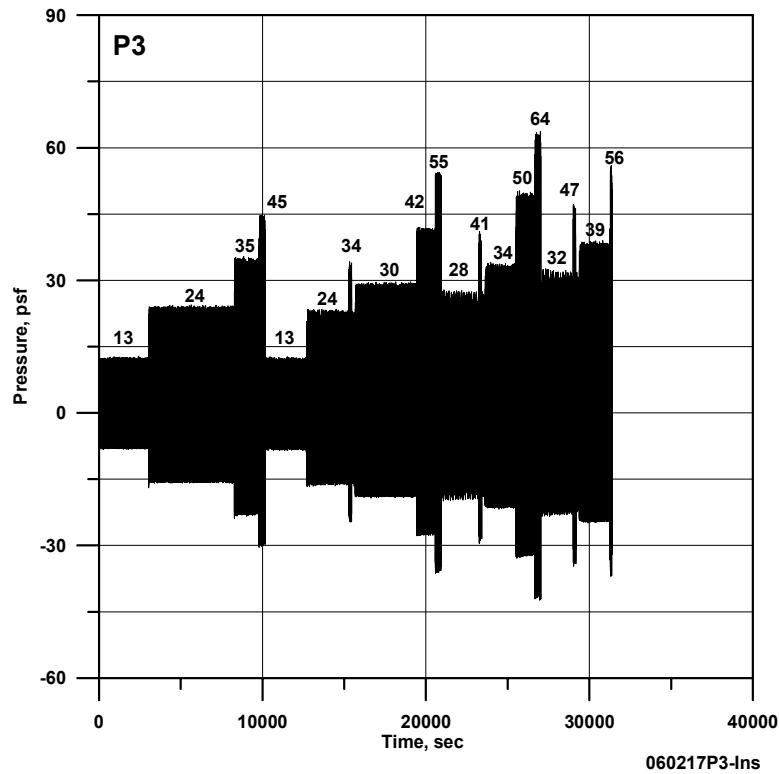
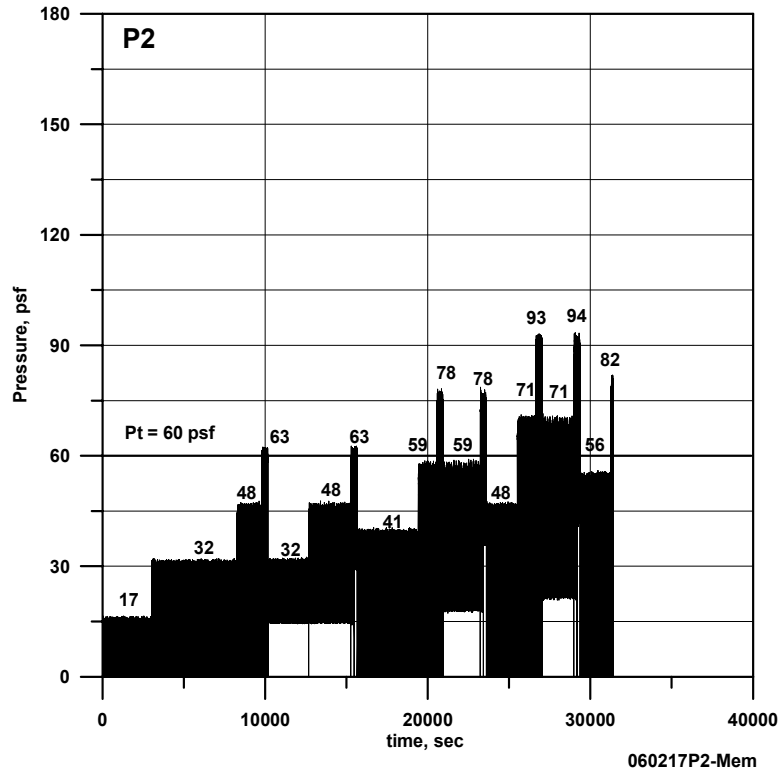
System 7 – Failure Mode



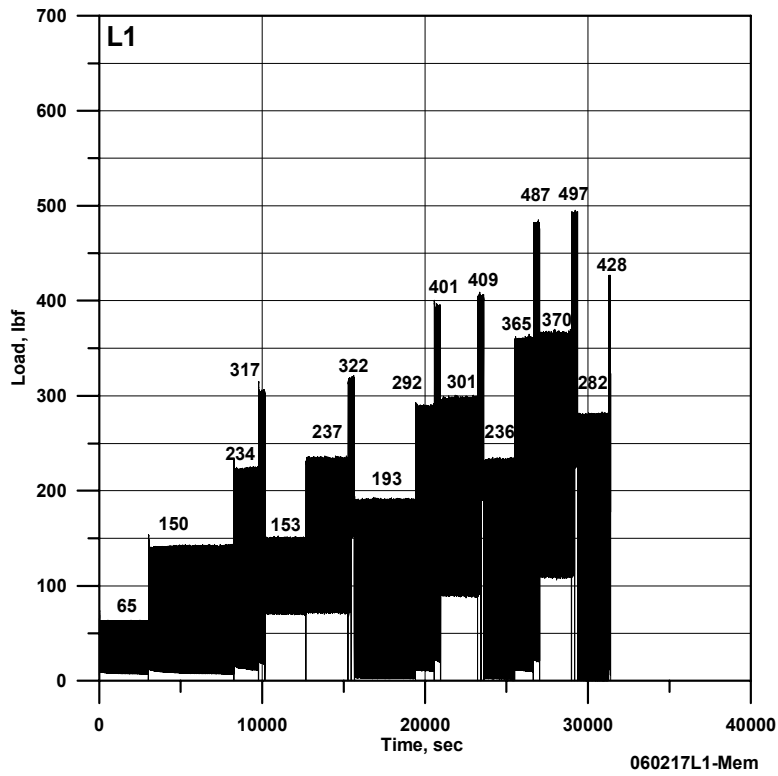
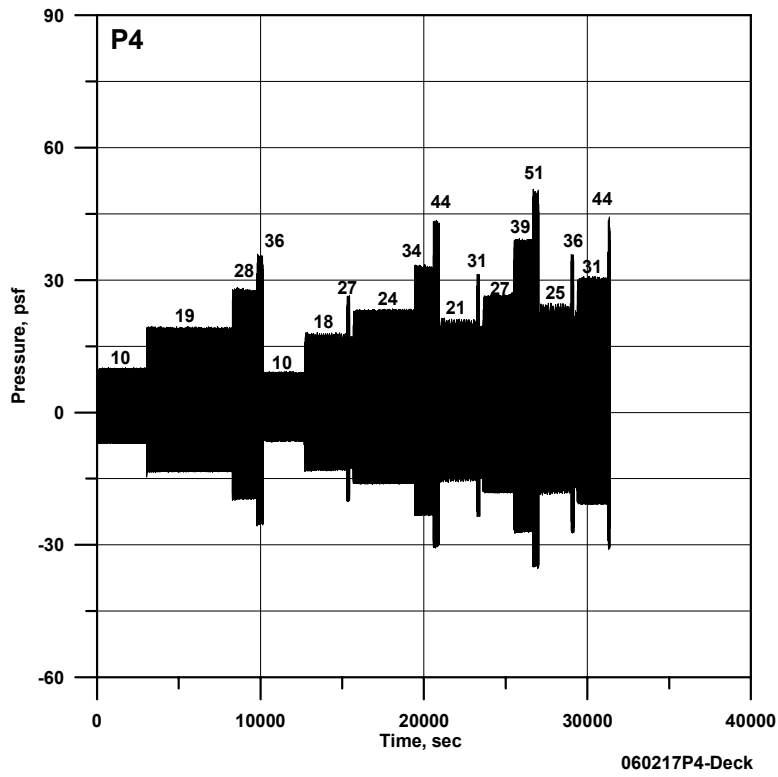
System 8- Measured Time Histories



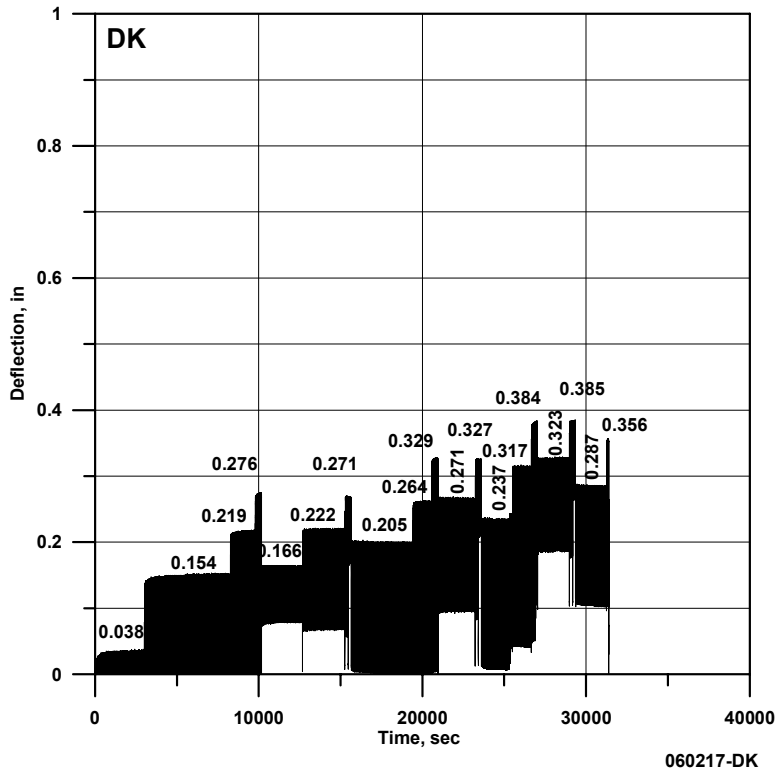
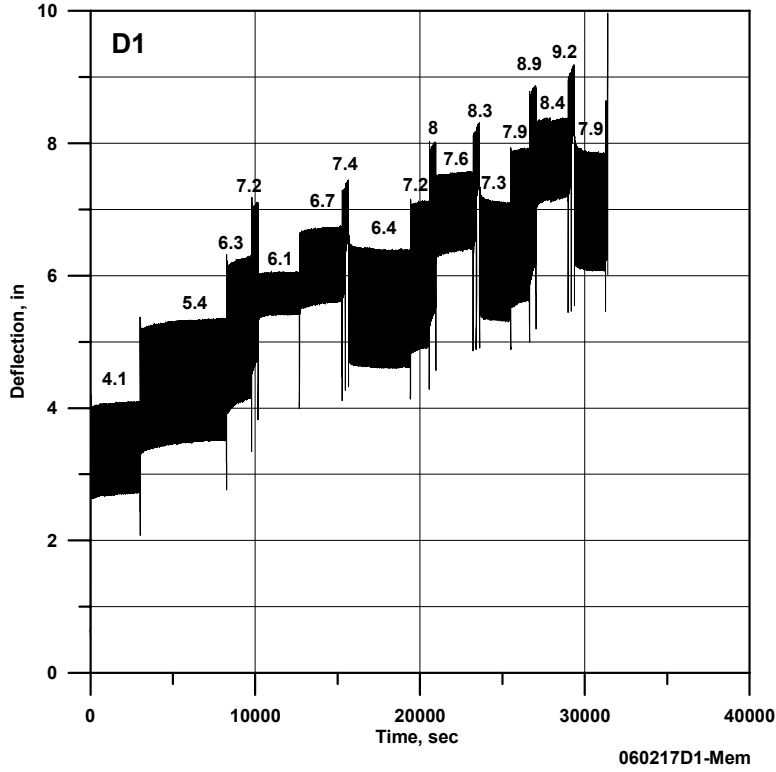
System 8- Measured Time Histories



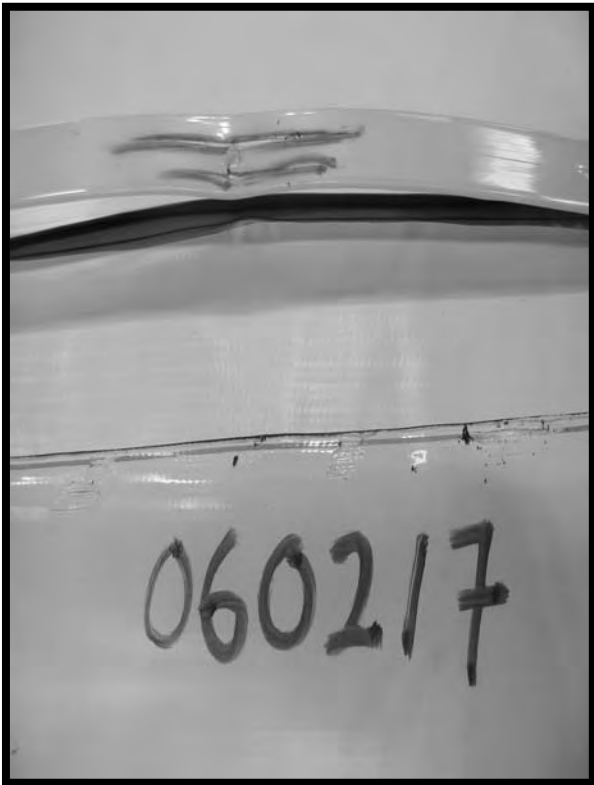
System 8- Measured Time Histories



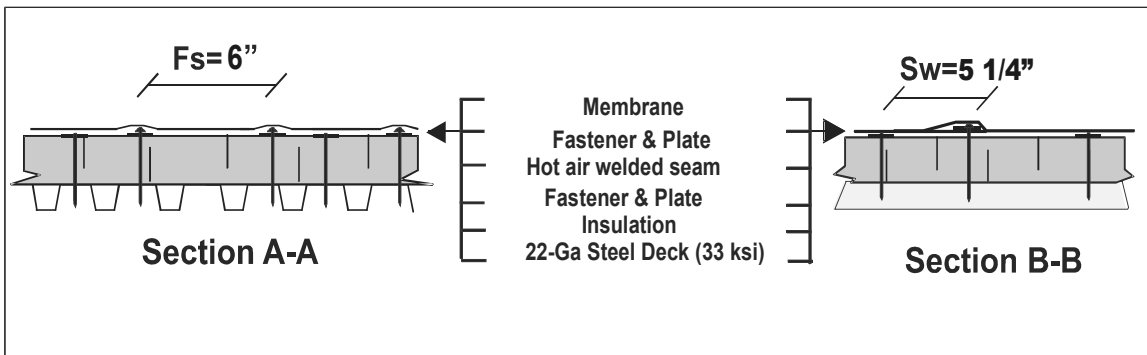
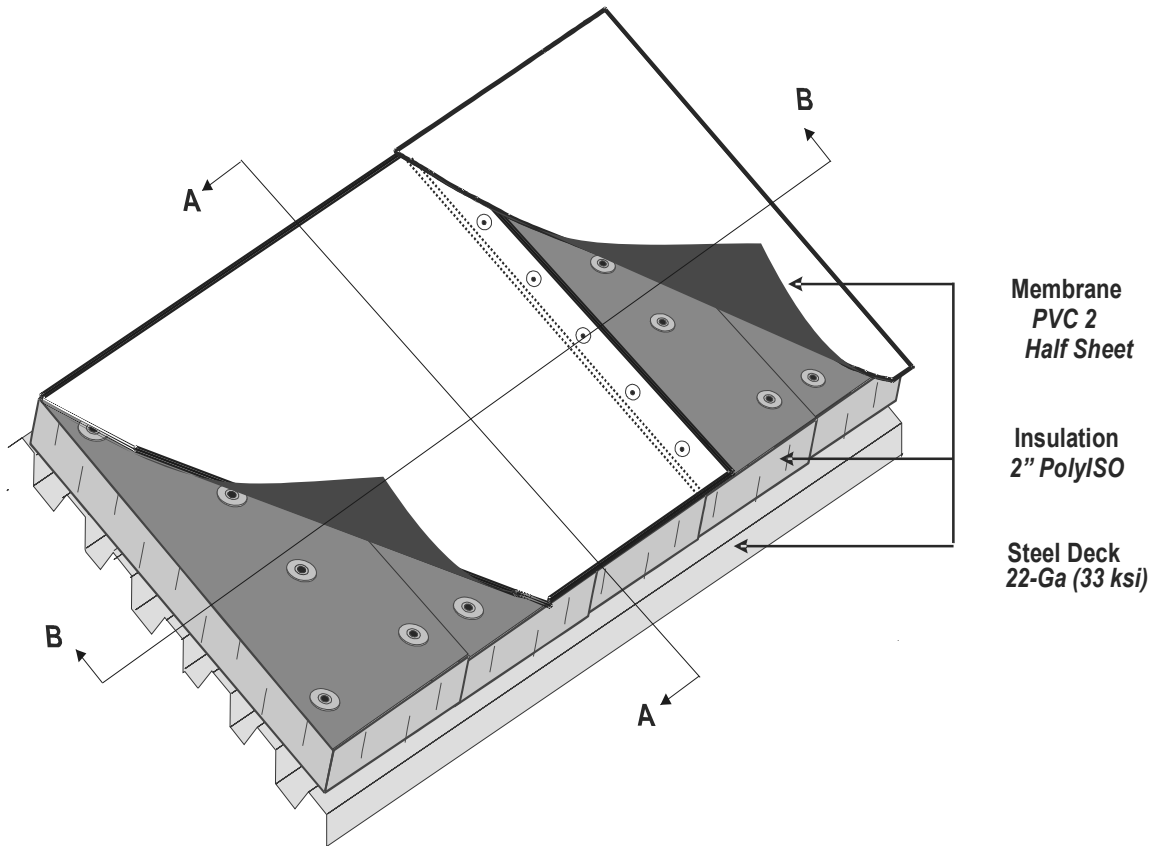
System 8- Measured Time Histories



System 8 – Failure Mode

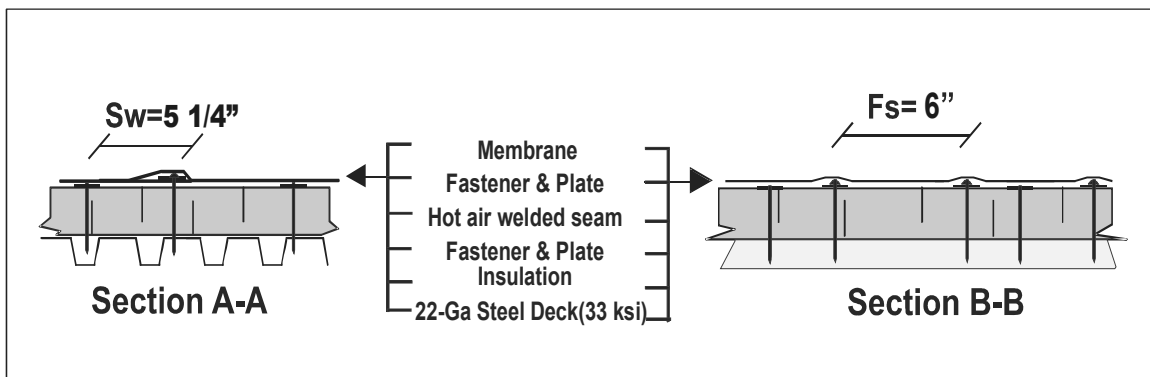
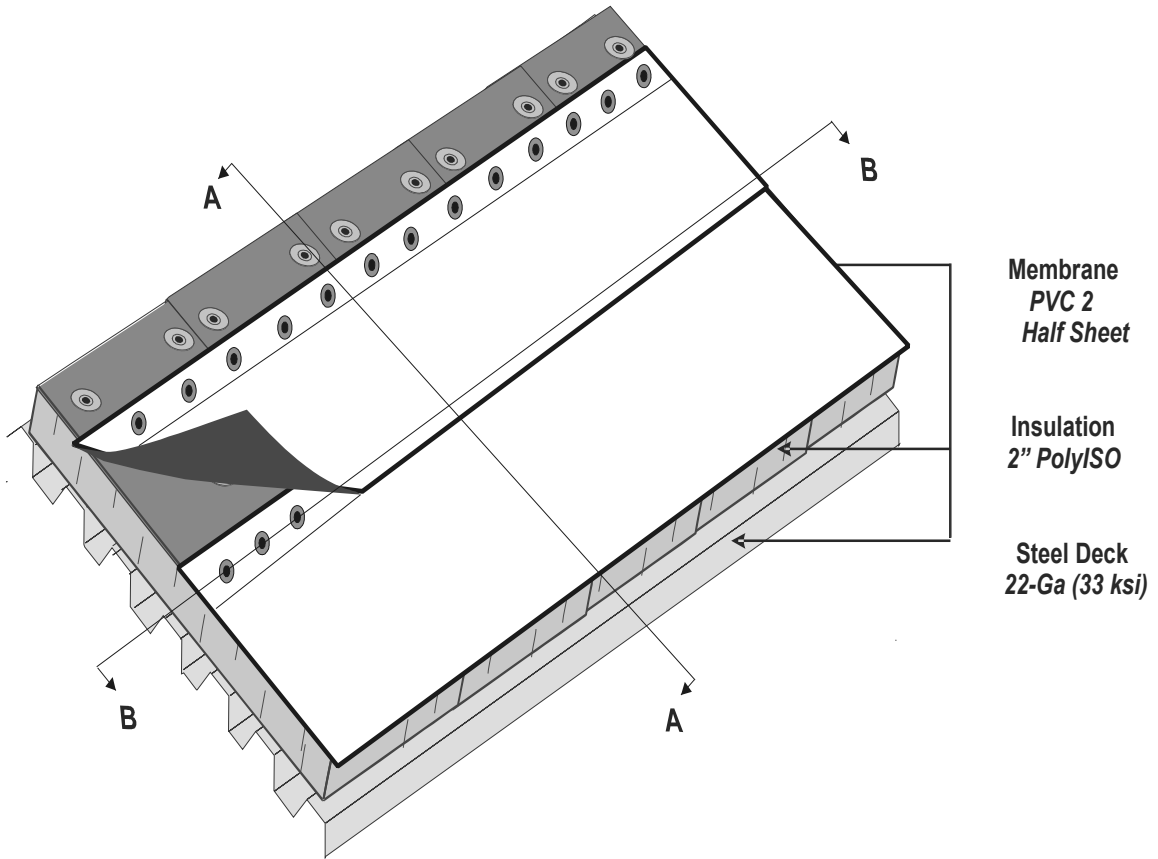


System 9– Components Layout

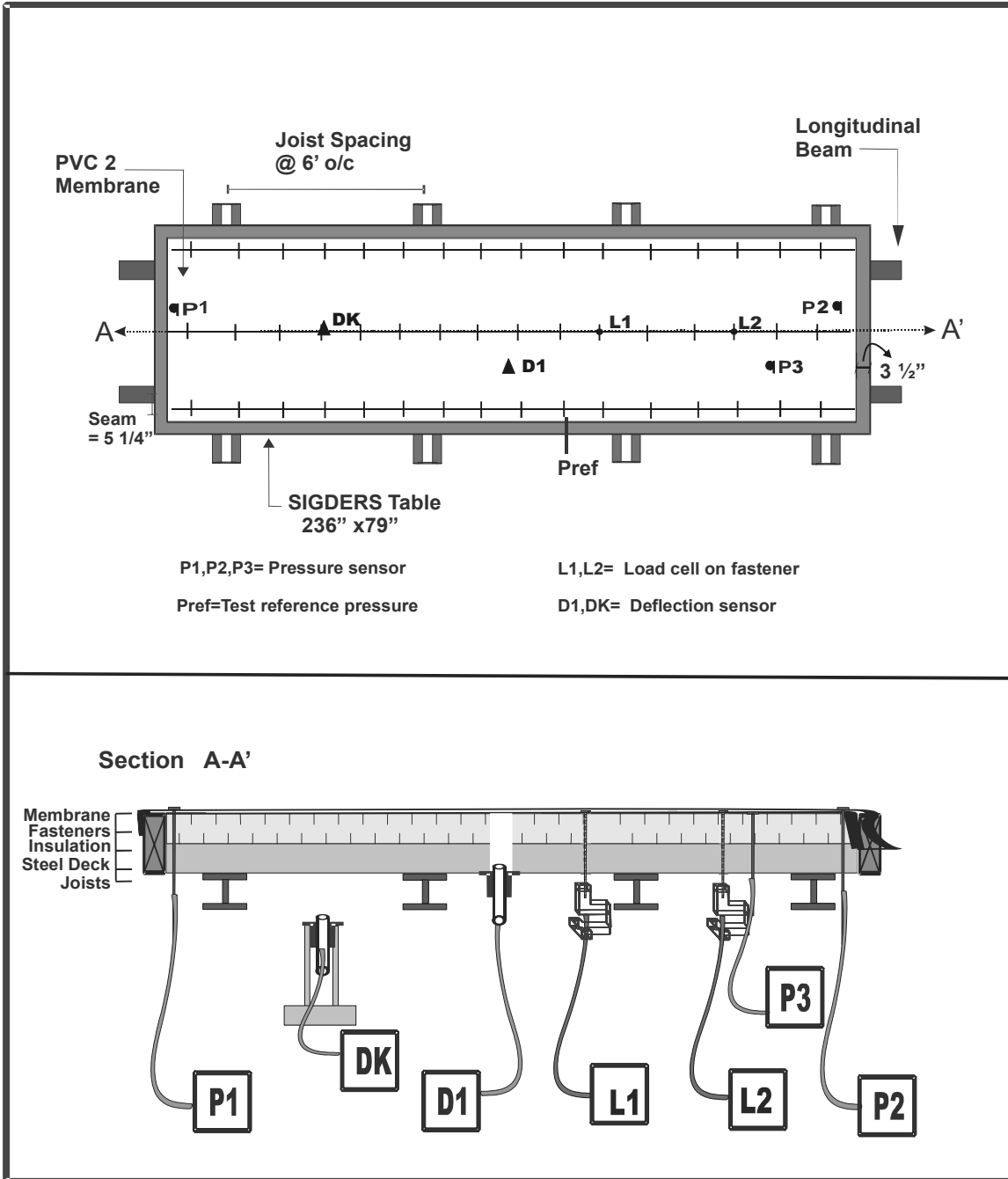


** Please refer to page 49 for instrumentation layout*

System 10- Components Layout



System 10– Instrumentation Layout



System 9 & 10- Installation

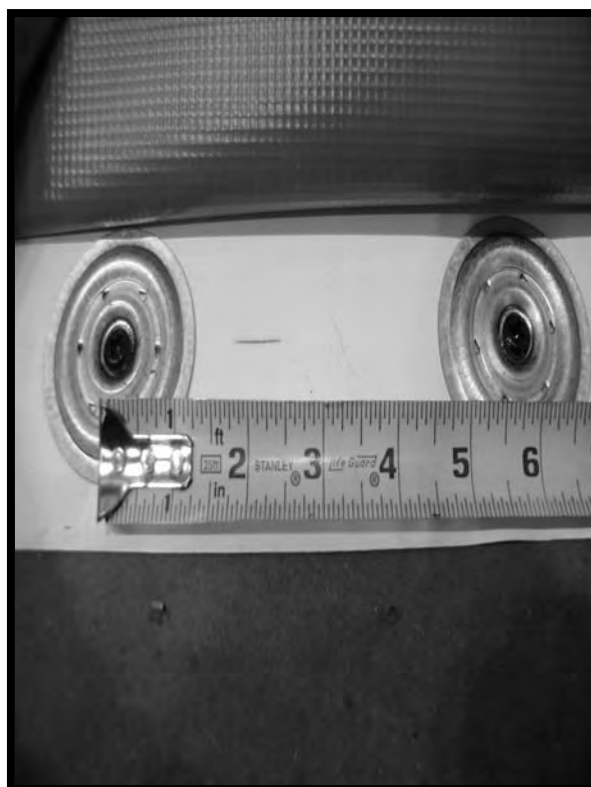
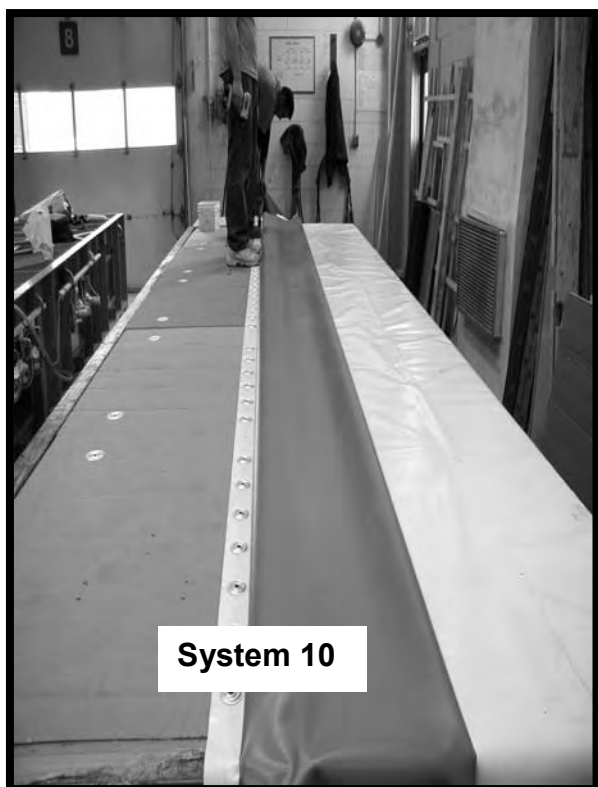


Table 9: Nominal physical and mechanical properties of the components for System 9 and System 10

Deck

Type	Profiled 22 gauge metal
Thickness*	22 Ga: 0.03" (0.76 mm), nominal; 0.80 mm, measured
Overall Depth	1 1/2" (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2006*	22 Ga (33 / 55 ksi) = 516lbf 2296 (N)
Source CANAM	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 5 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type None	
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Membrane

Type PVC										
Width	76" (1930 mm)									
Thickness	45 mil (1.1 mm)									
Tensile Property as per ASTM D 751-2000*	<table border="0"> <tr> <td></td> <td align="center">MD</td> <td align="center">XD</td> </tr> <tr> <td>Breaking strength, KN (lbf)</td> <td align="center">1.55 (348)</td> <td align="center">1.25 (281)</td> </tr> <tr> <td>Elongation at Max. Load, %</td> <td align="center">31.5</td> <td align="center">23.9</td> </tr> </table>		MD	XD	Breaking strength, KN (lbf)	1.55 (348)	1.25 (281)	Elongation at Max. Load, %	31.5	23.9
	MD	XD								
Breaking strength, KN (lbf)	1.55 (348)	1.25 (281)								
Elongation at Max. Load, %	31.5	23.9								

Attachment

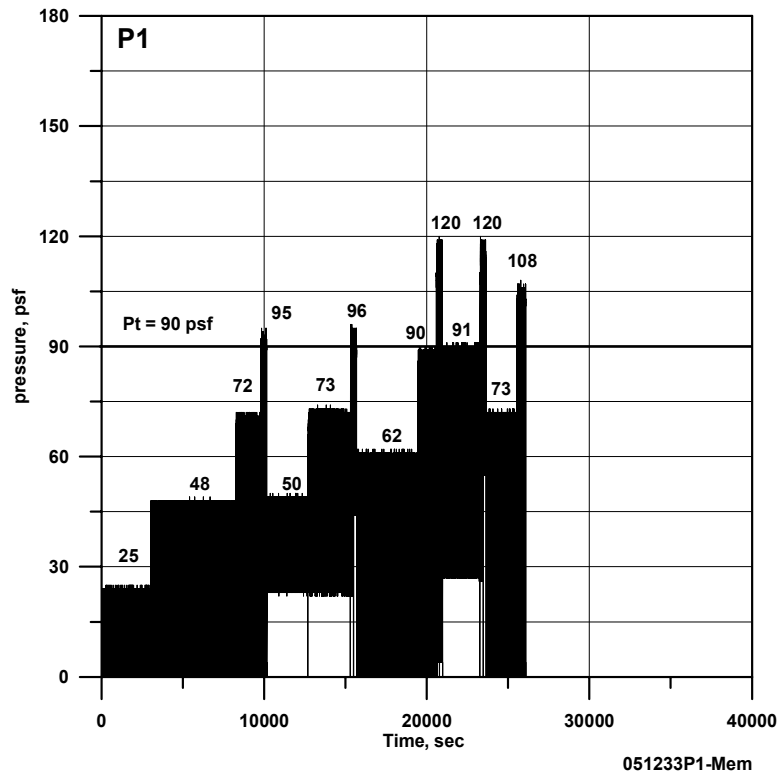
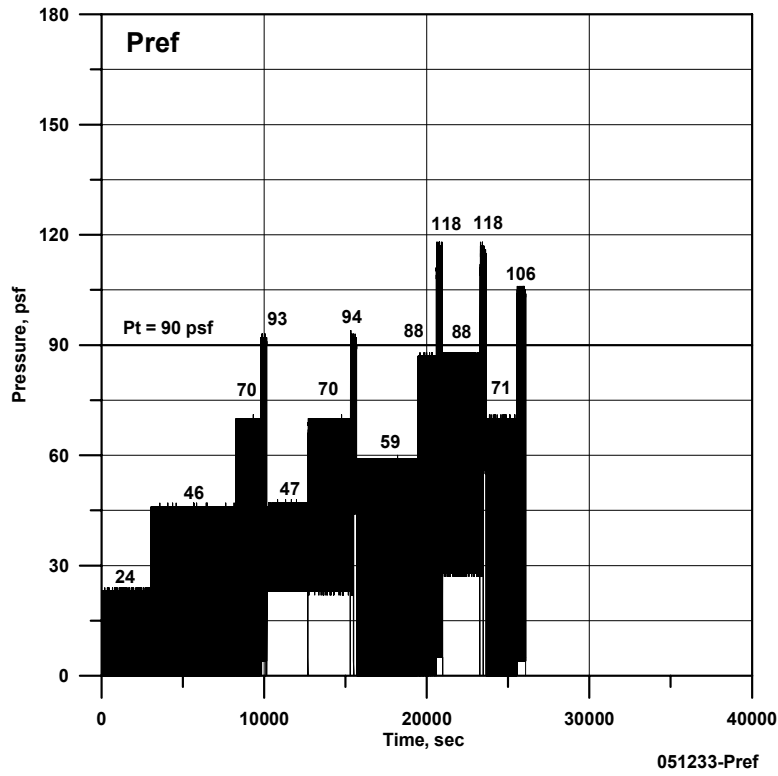
Type	Mechanical fasteners with plates
Fastener	3" (76mm), #15
Polymer Batten Bar	2 3/8" (60 mm) round plate with barb
Fastener Row Spacing	32 3/4" (832 mm)
Fastener Spacing	6" (152 mm)
Slippage Control	Yes

Seam

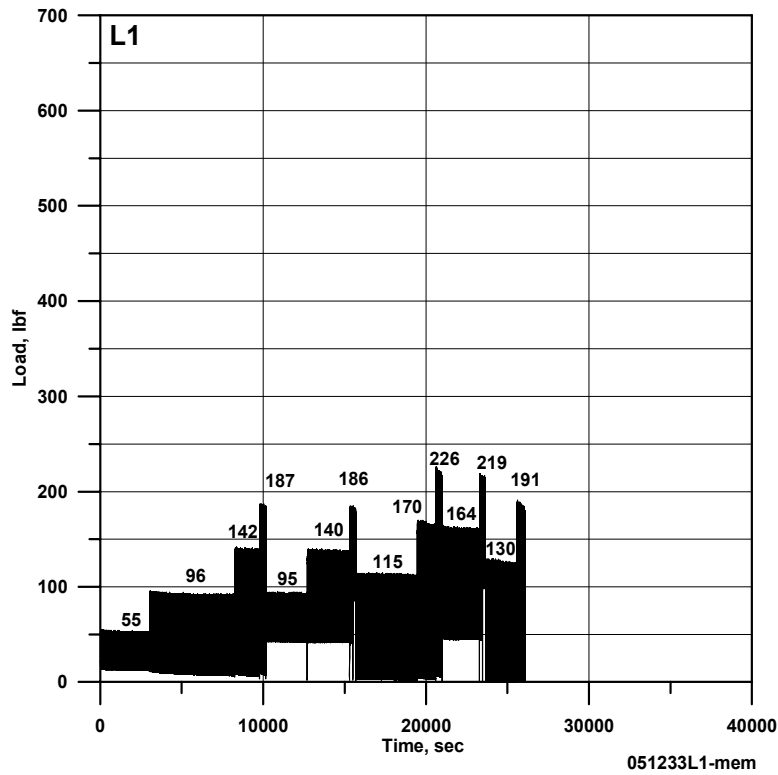
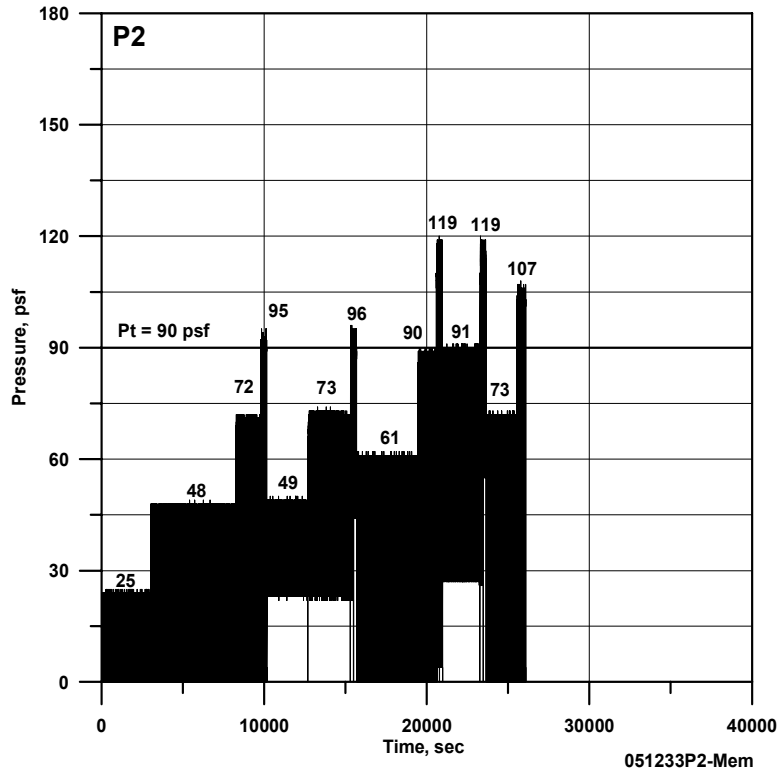
Type	Hot air welding (One side weld)
Seaming Width	Overlap = 5 1/4" (133 mm) Temperature: 540°C Speed: 3m/min

* NRC Test Results

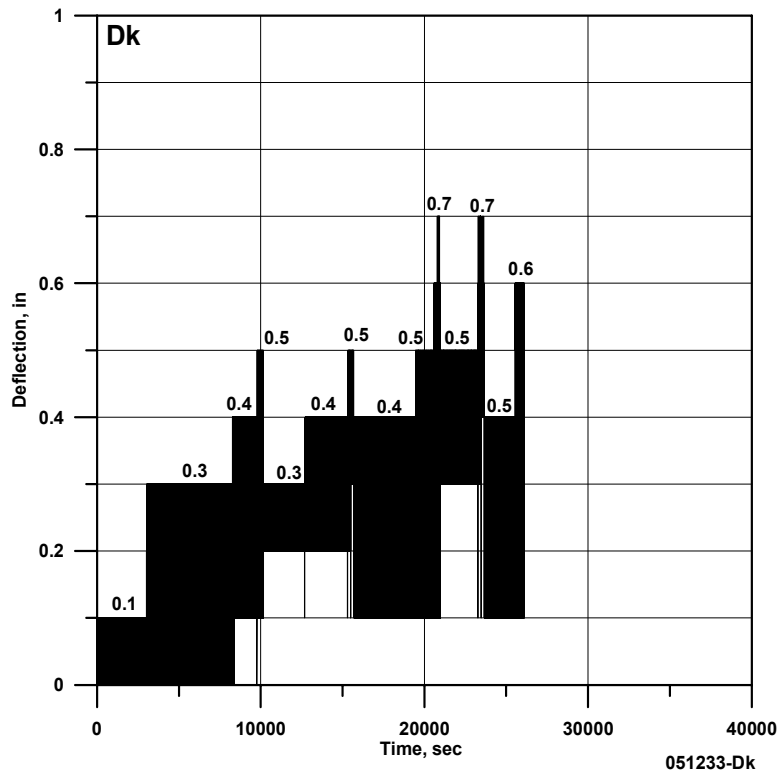
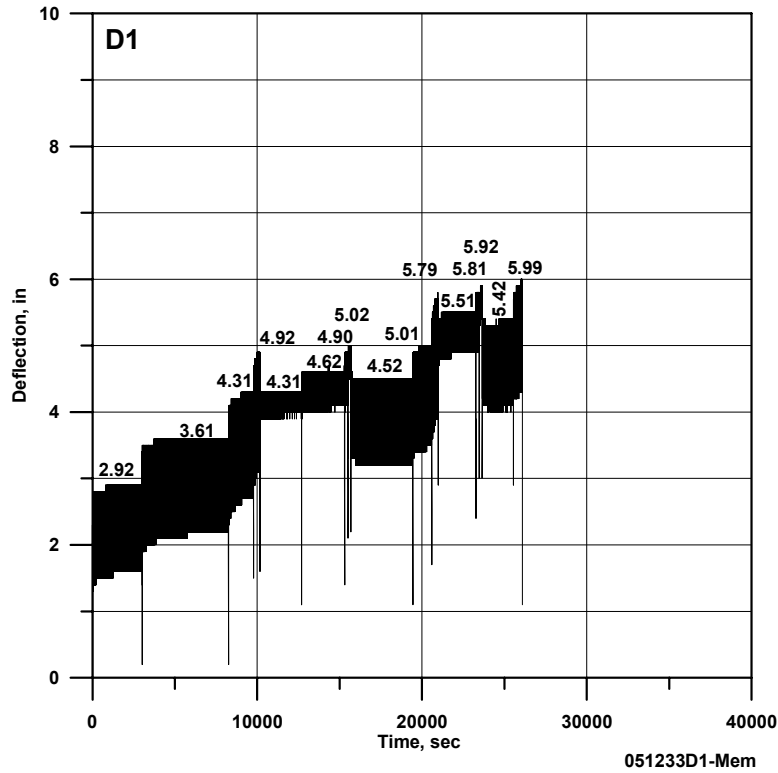
System 9- Measured Time Histories



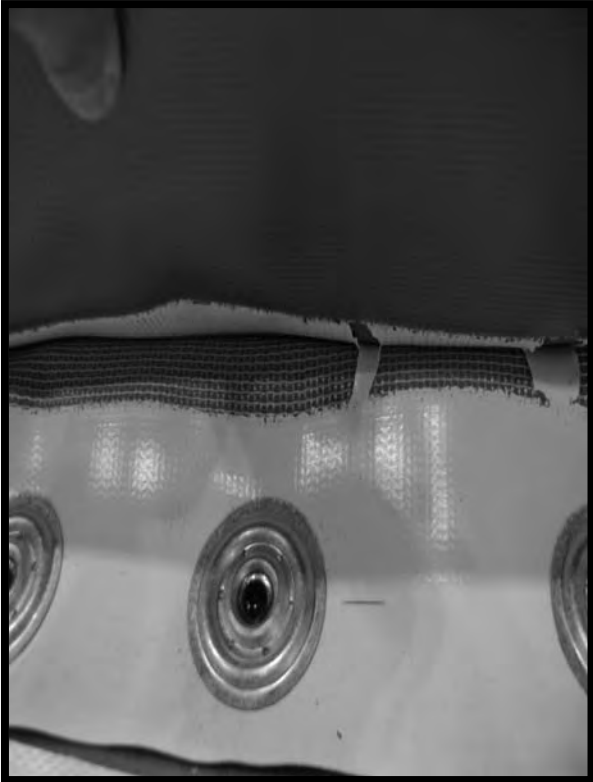
System 9- Measured Time Histories



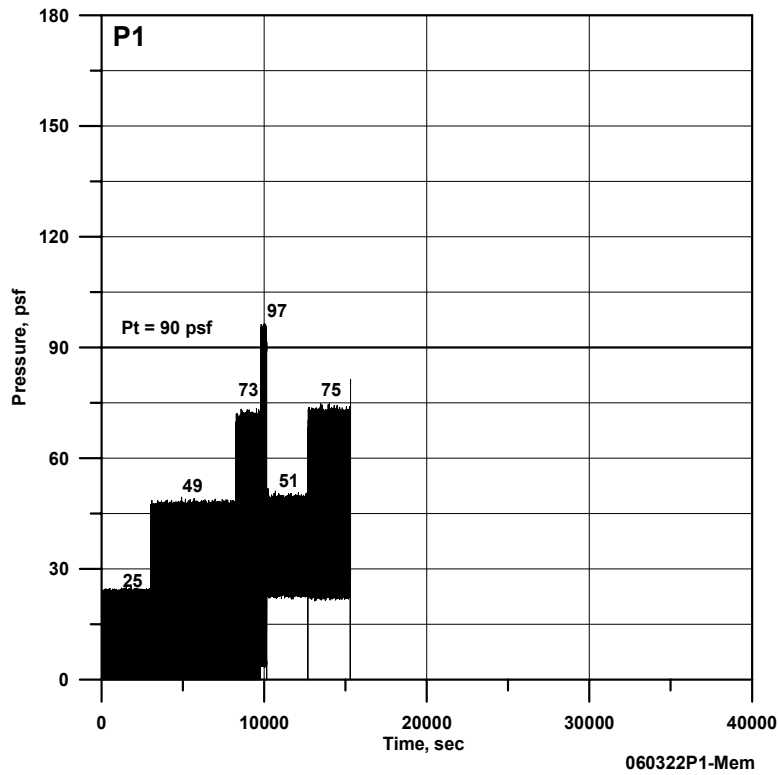
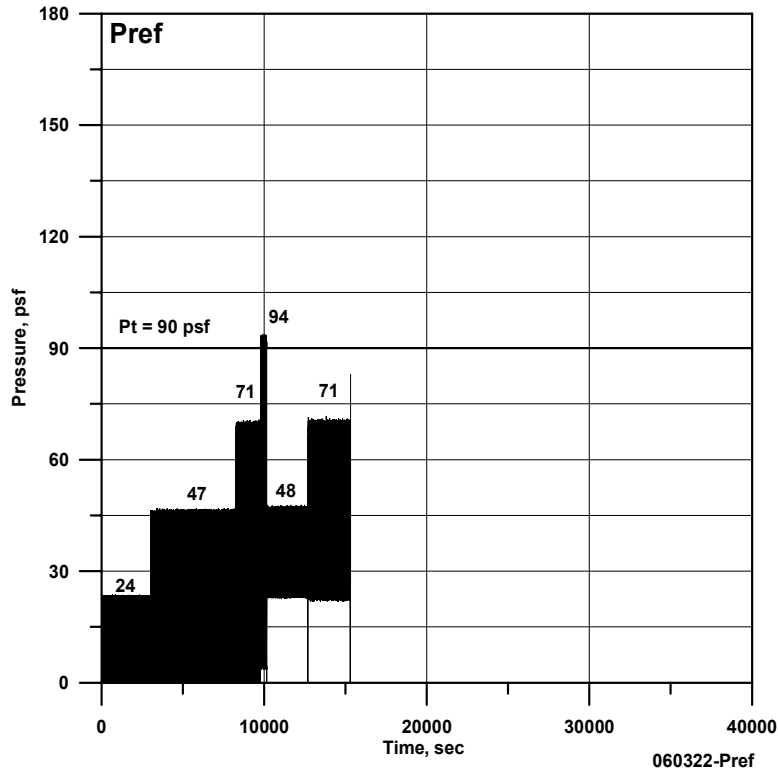
System 9– Measured Time Histories



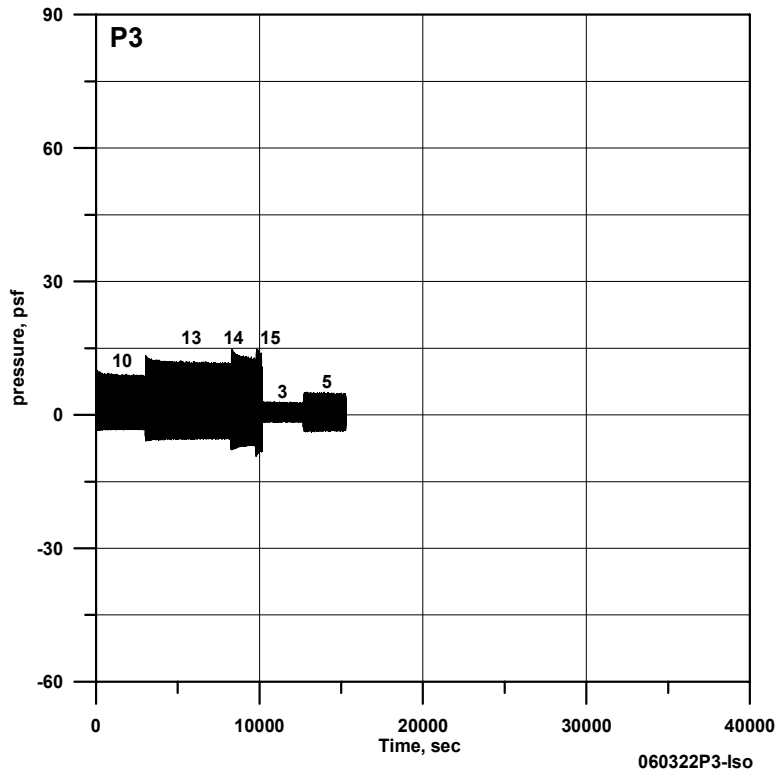
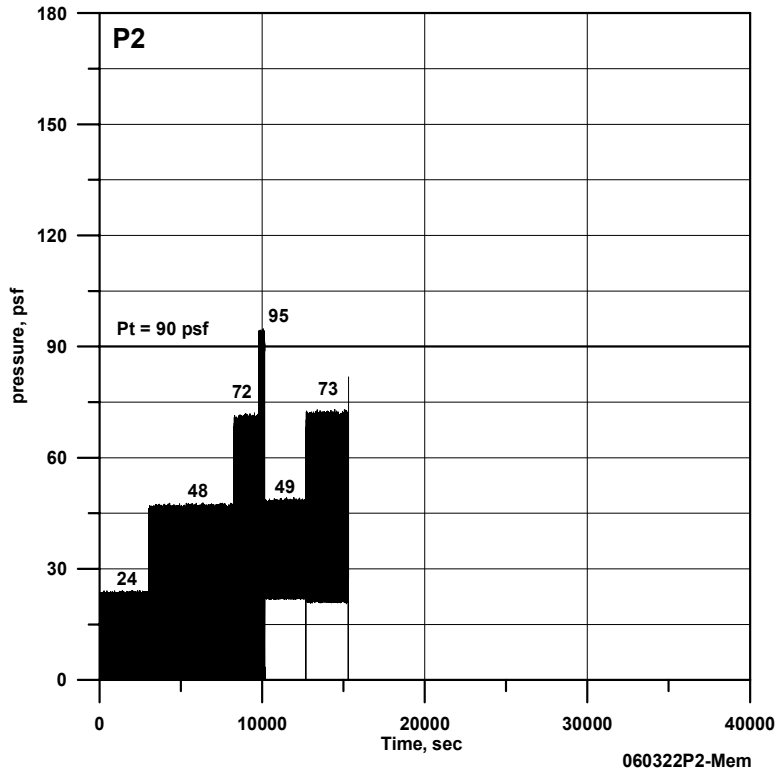
System 9 – Failure Mode



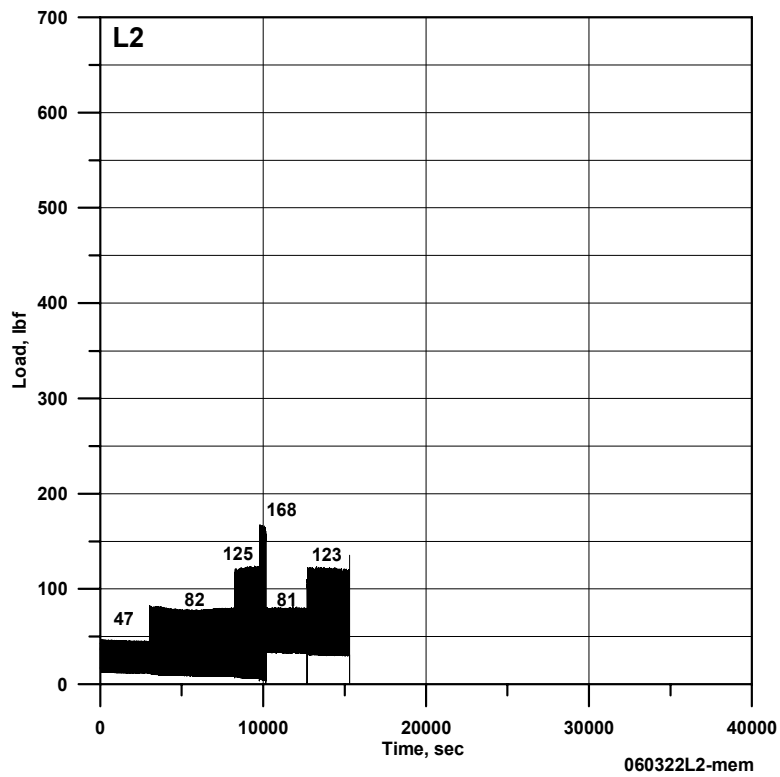
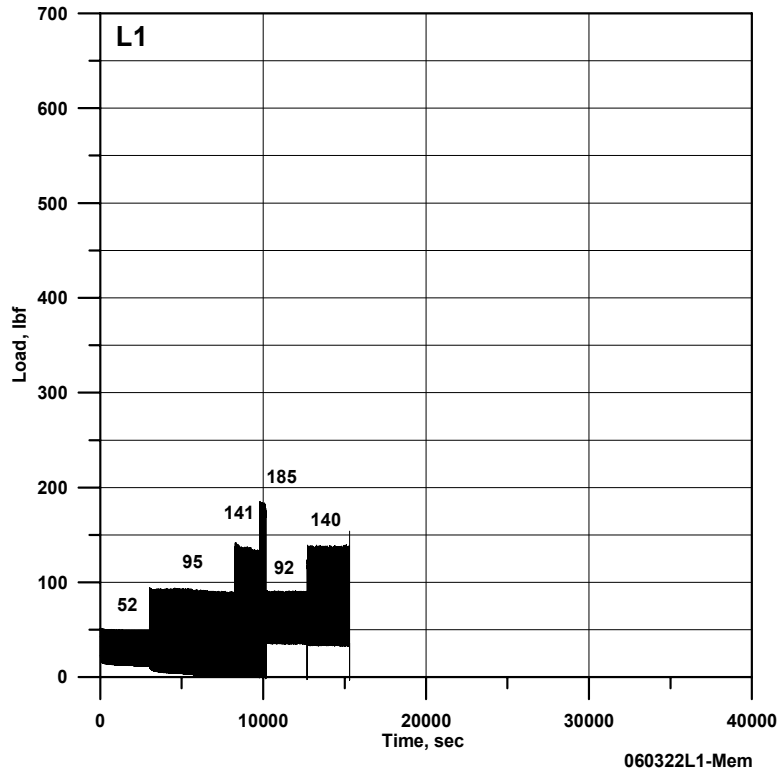
System 10- Measured Time Histories



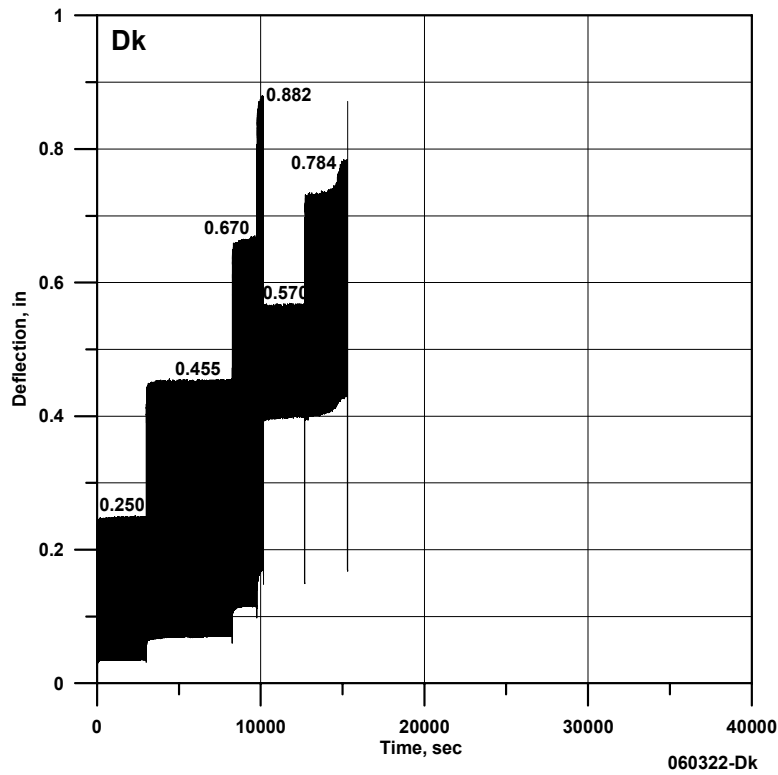
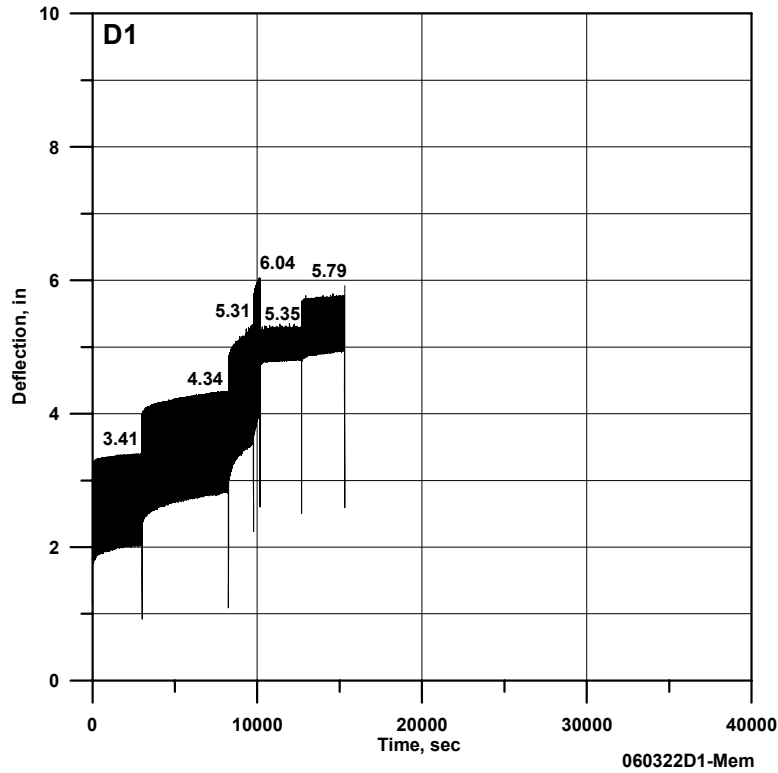
System 10- Measured Time Histories



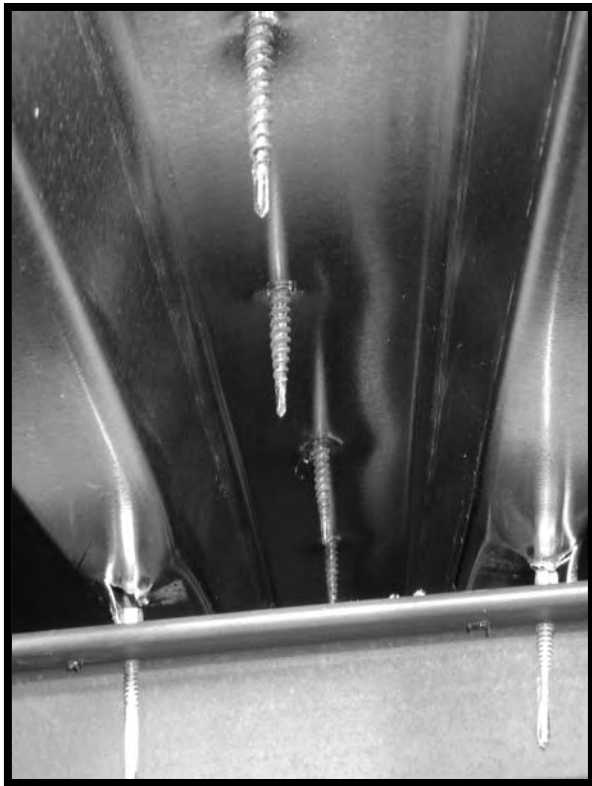
System 10- Measured Time Histories



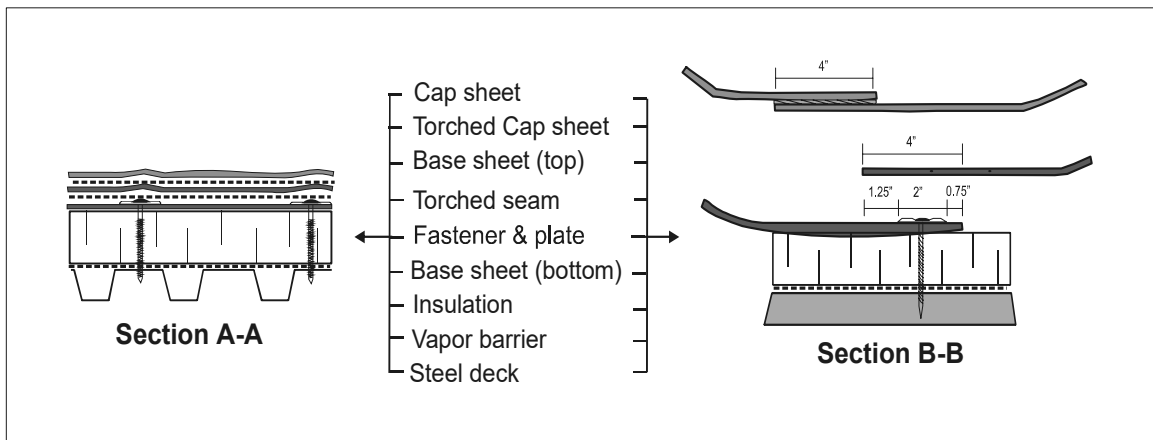
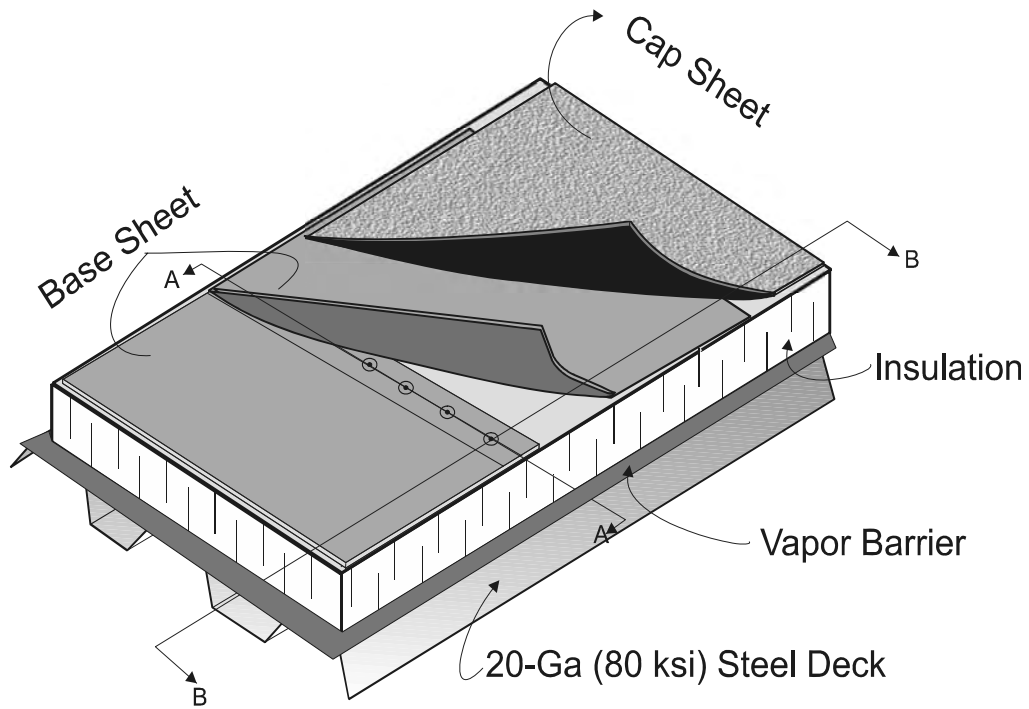
System 10- Measured Time Histories



System 10 – Failure Mode

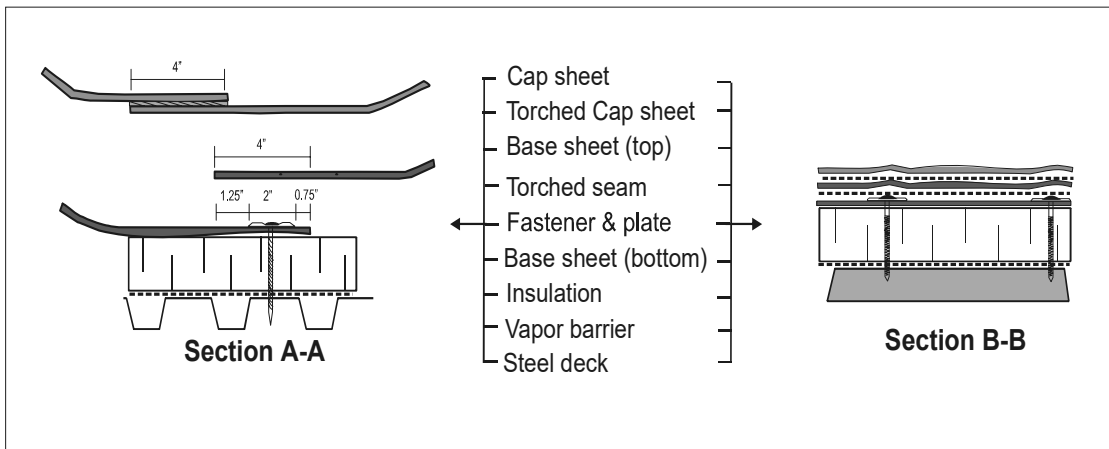
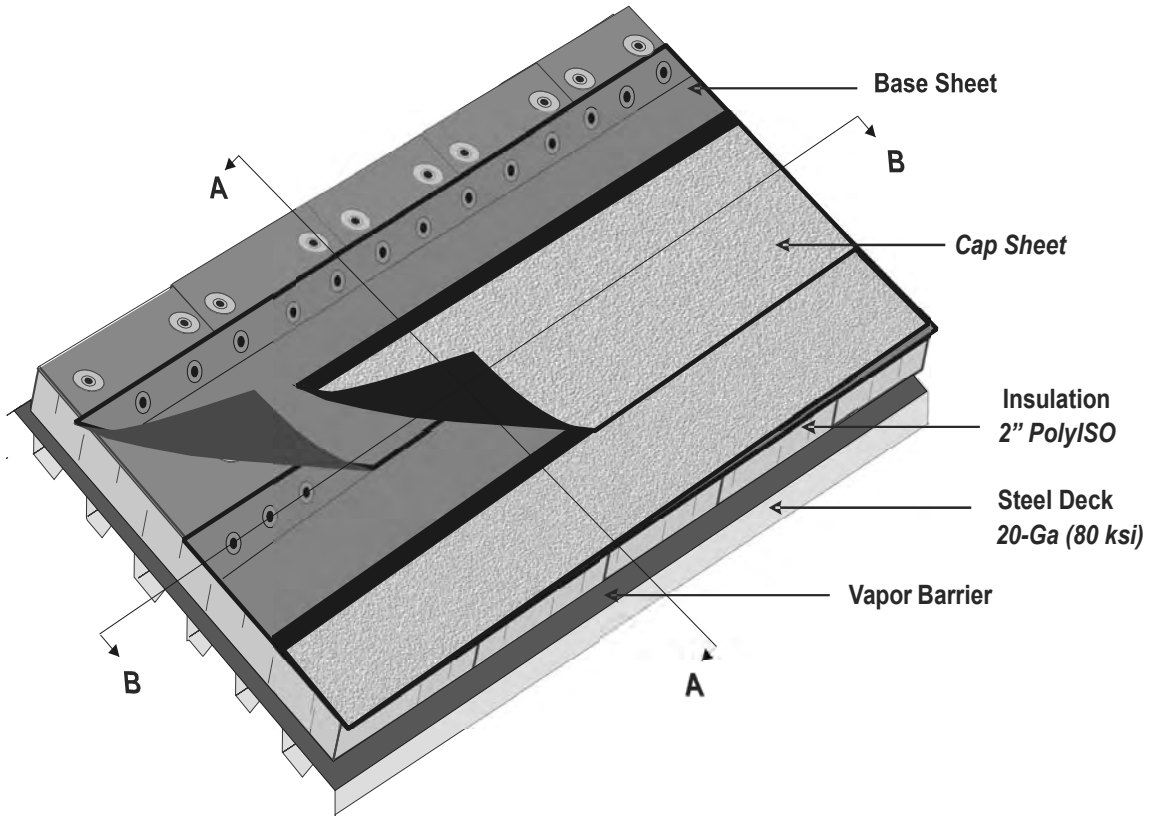


System 11 – Components Layout



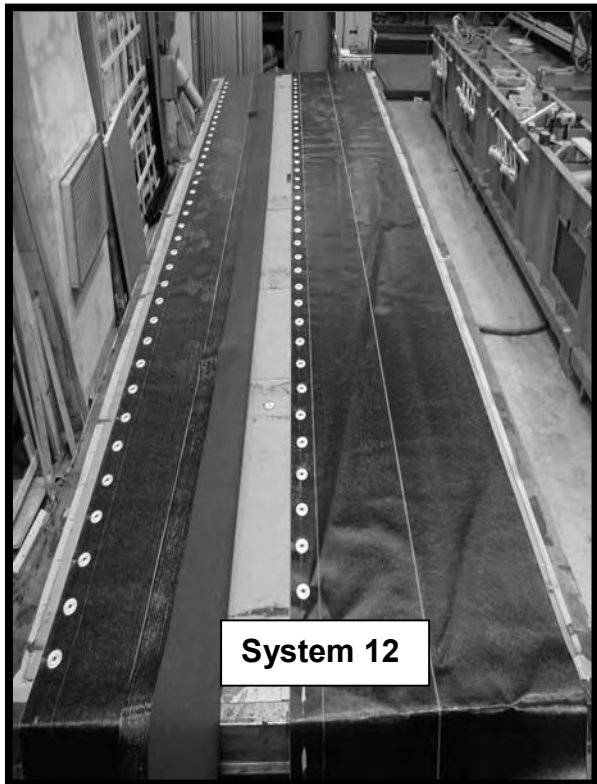
** Please refer to page 29 for instrumentation layout*

System 12- Components Layout



*** Please refer to page 69 for instrumentation layout**

System 11 &12- Installation



System 11 &12- Installation



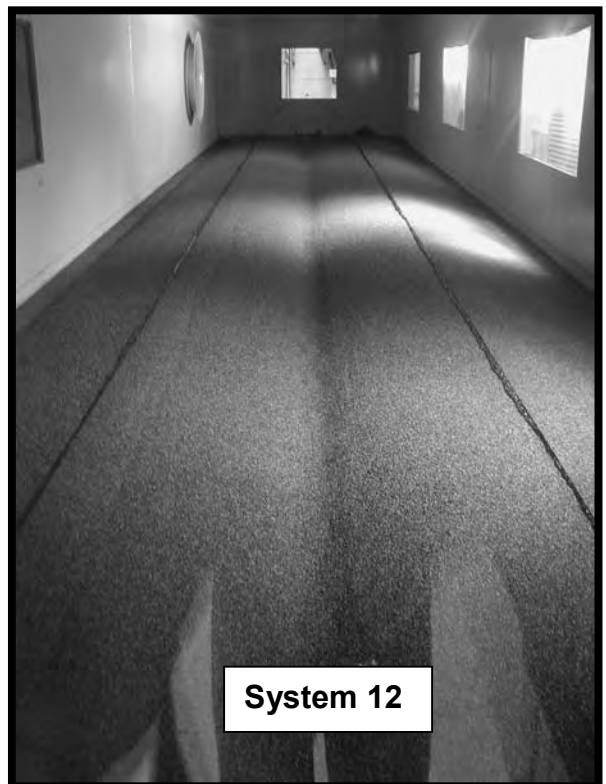
System 11



System 12



System 11



System 12

Table 10: Nominal physical and mechanical properties of the components for System 11 and System 12

Deck

Type	Profiled 20 gauge metal
Thickness*	0.036" (0.91 mm), nominal; 0.94 mm, measured
Overall Depth	1.5" (38 mm)
Flute Spacing	5.9" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2004*	20 Ga (80 / 107 ksi) = 651 lbf (2894 N)
Source Canam	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 5 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type	Vapor barrier, Sopra Vapor
Type	

Membrane

Type	Mod. Bit., Base Sheet and Cap Sheet		
Width 39"			
Thickness	Base Sheet (2.2 mm), Cap Sheet (3.3 mm)		
Tensile Property as per CGSB-37.56-M-97, 23°C* (Base Sheet)	Max. Load (N/mm)	MD 15.4	XD 13.7
	Elongation at Max Load (%)	62	58
	Strain energy (KN/mm)	7.3	6.5
Tensile Property as per CGSB-37.56-M-97, 23°C* (Cap Sheet)	Max. Load (N/mm)	15.6	13.9
	Elongation at Max Load (%)	55	59
	Strain energy (KN/mm)	6.9	6.6

Attachment

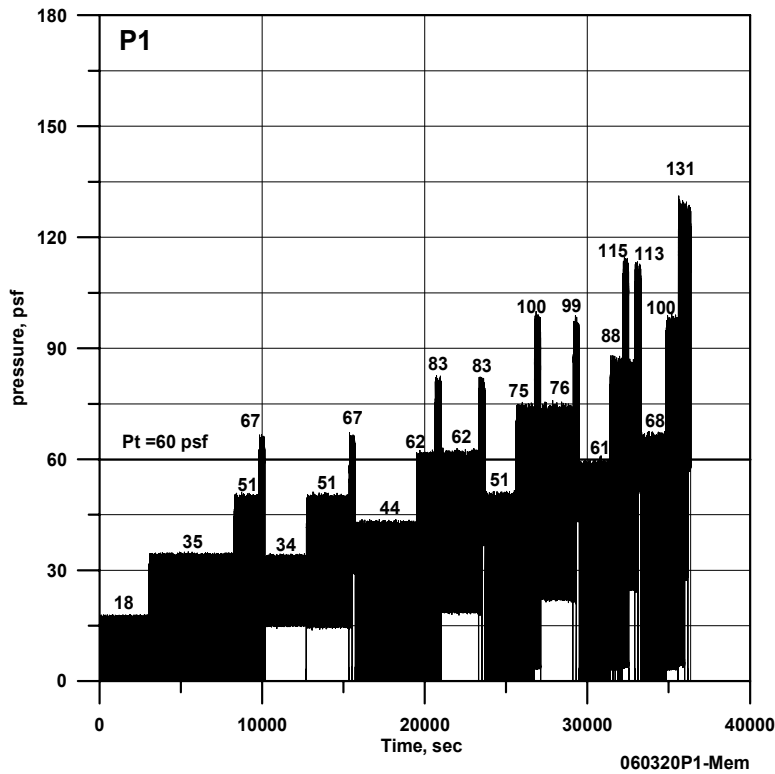
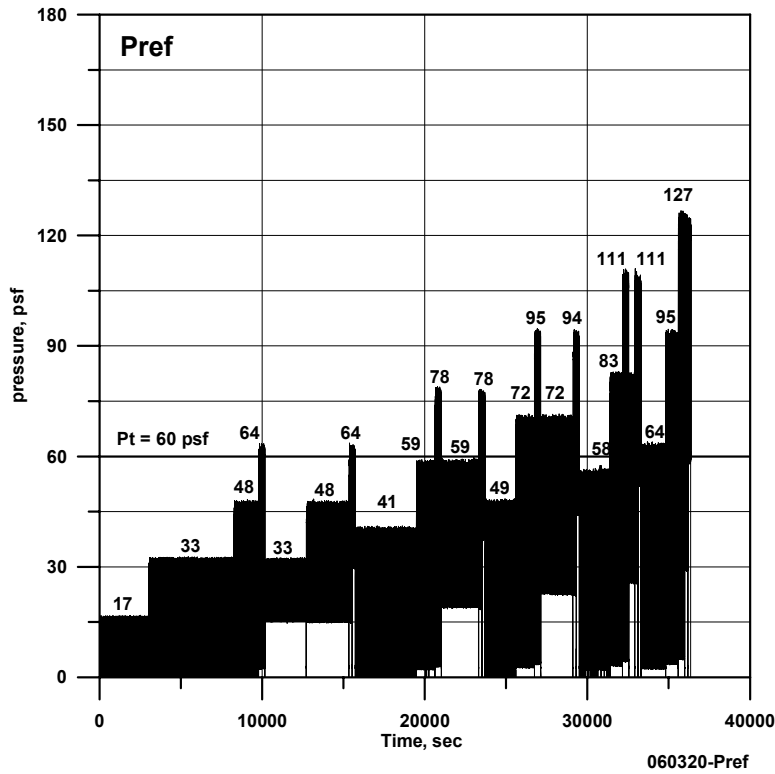
Type	Mechanical fasteners with Plates
Fastener	3" (76mm), # 14
Polymer Batten	2" (51 mm) dia. Metal Plate
Fastener Row Spacing	35" (889 mm)
Fastener Spacing	6" (152 mm)

Seam

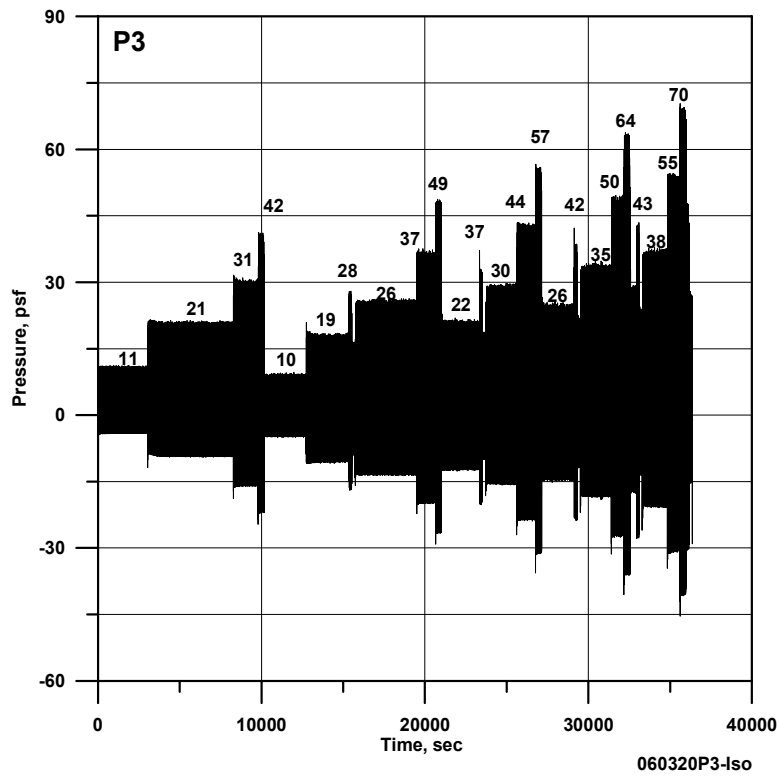
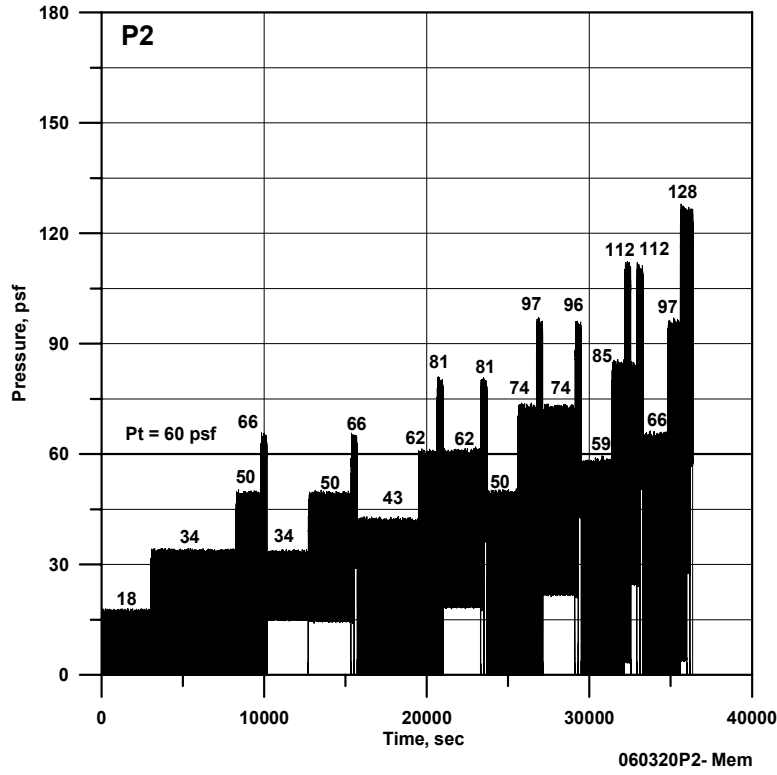
Type Torching	
Seaming Width	Overlap = 4" (102 mm)

* NRC Test Results

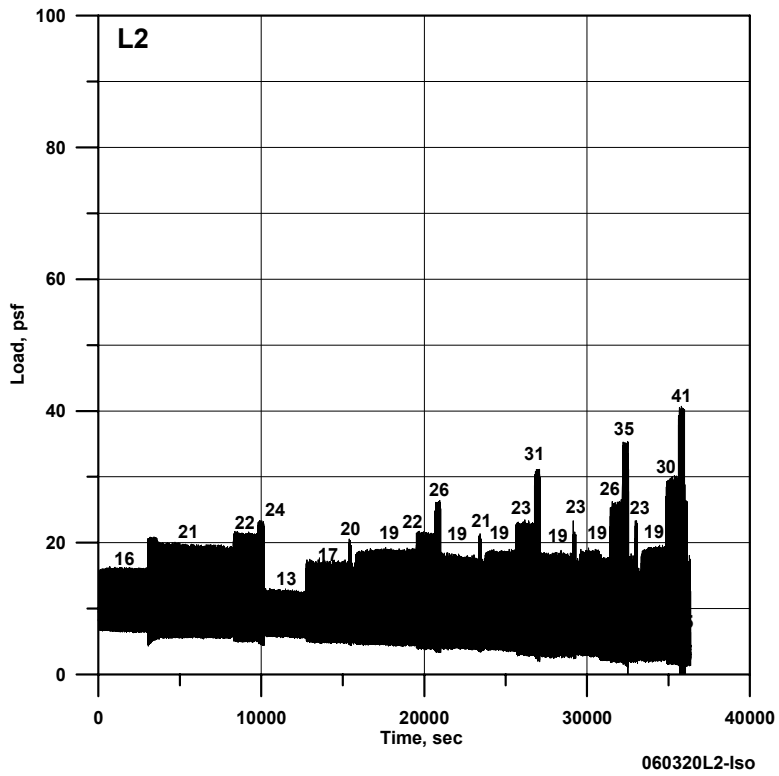
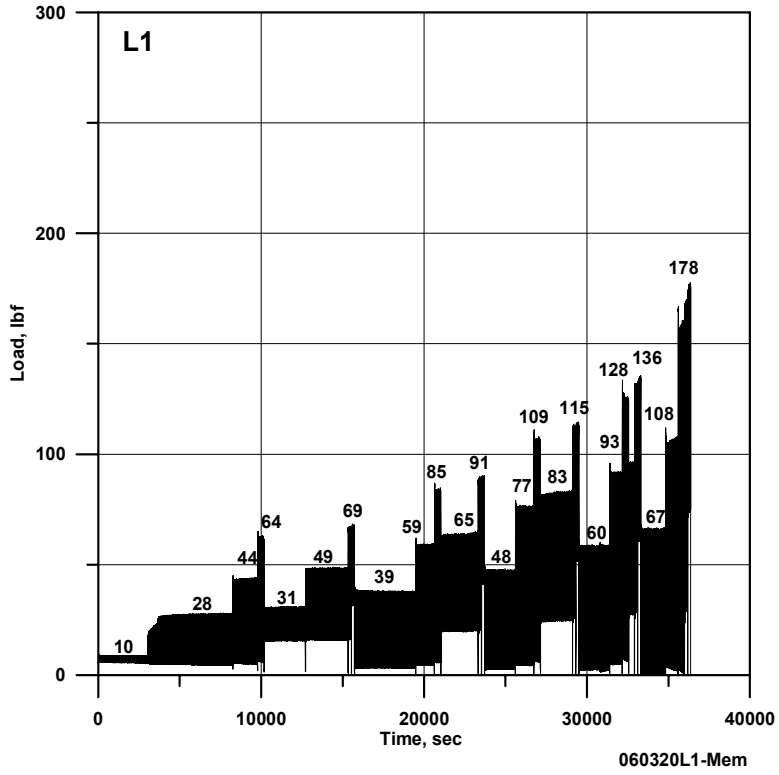
System 11- Measured Time Histories



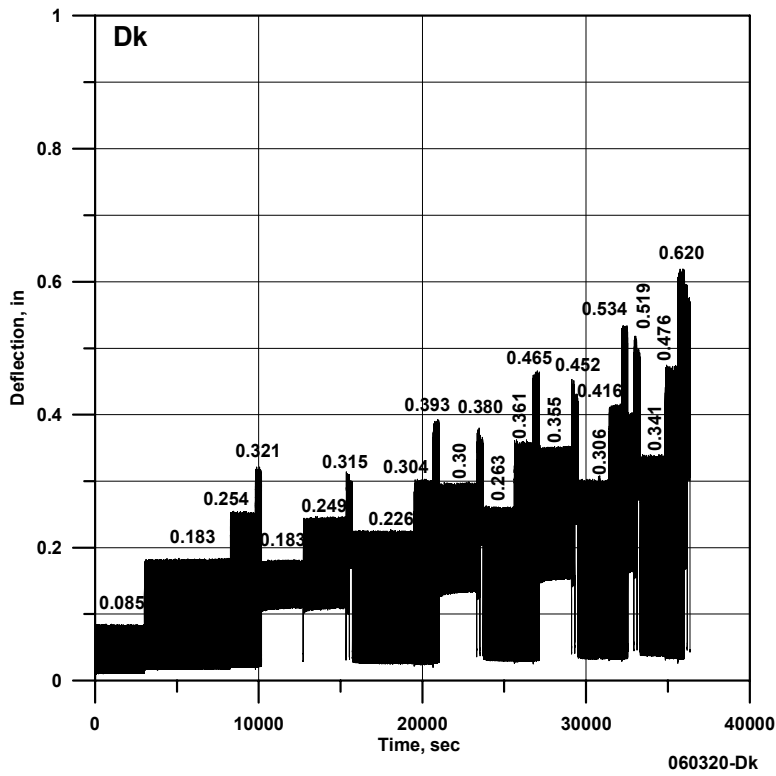
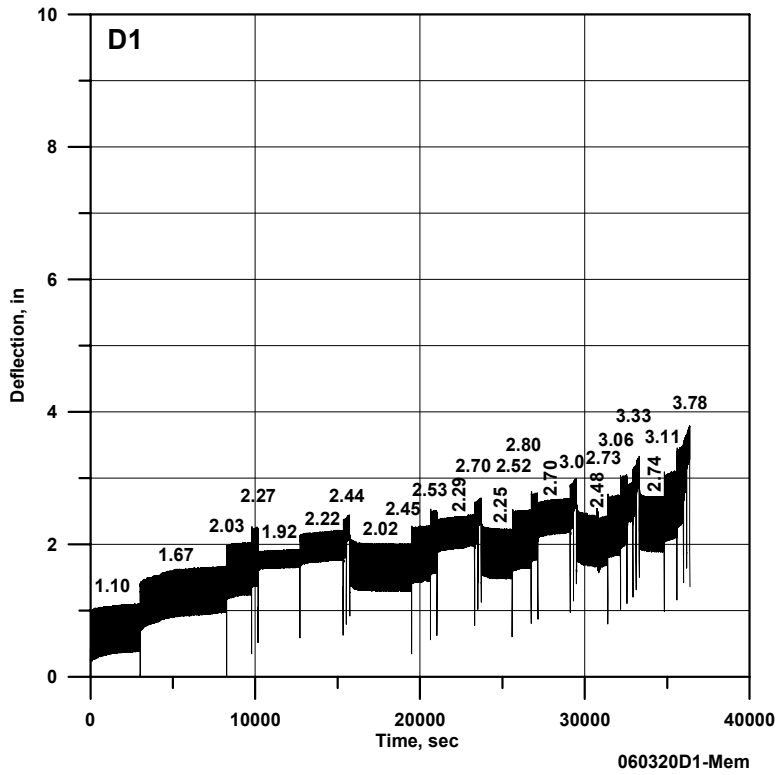
System 11- Measured Time Histories



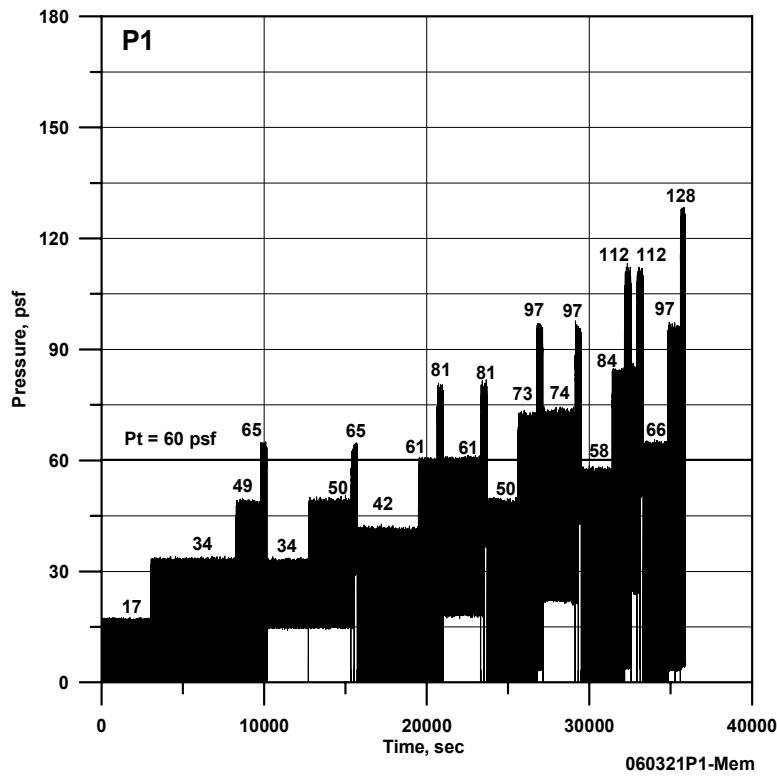
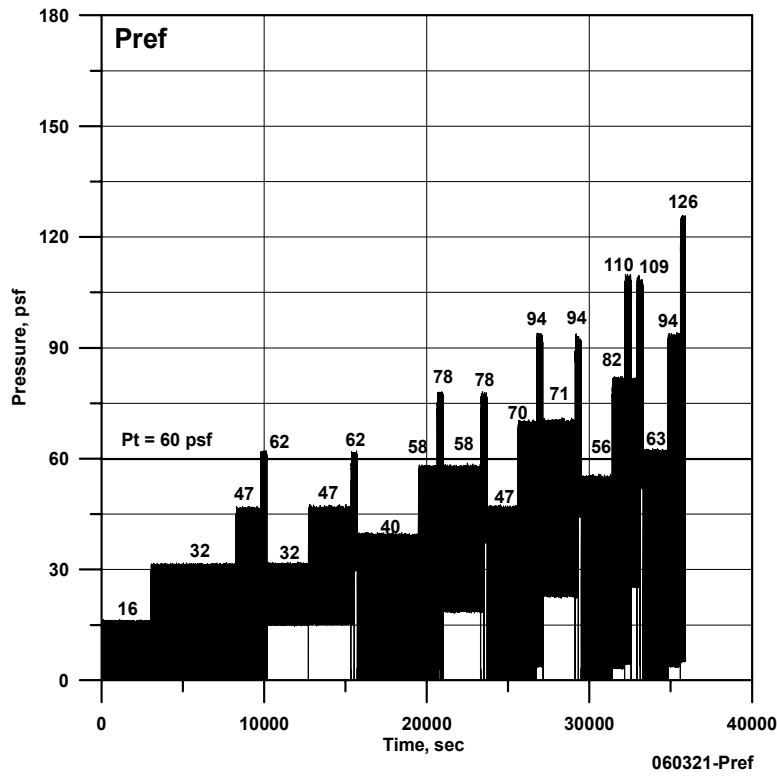
System 11- Measured Time Histories



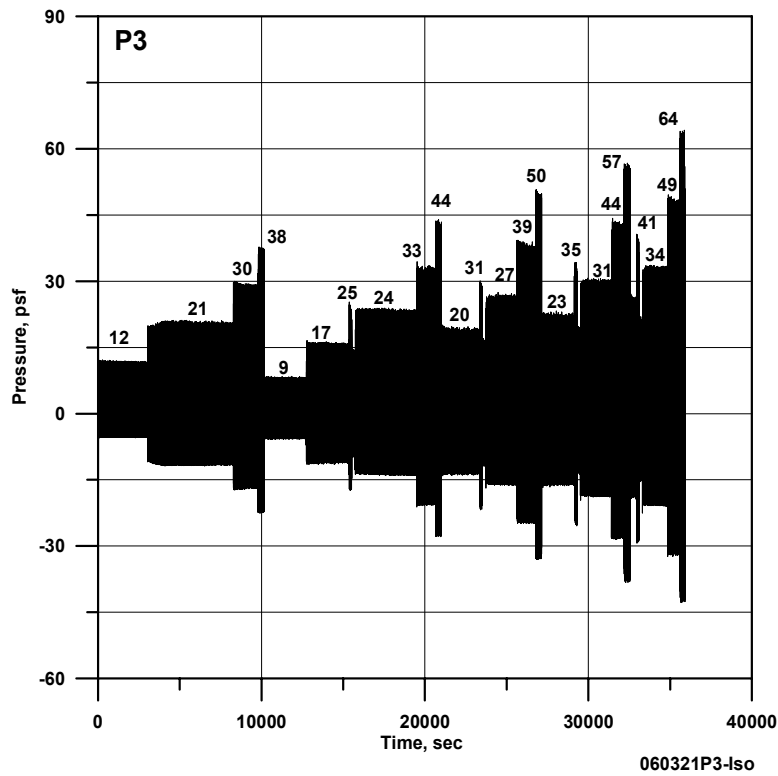
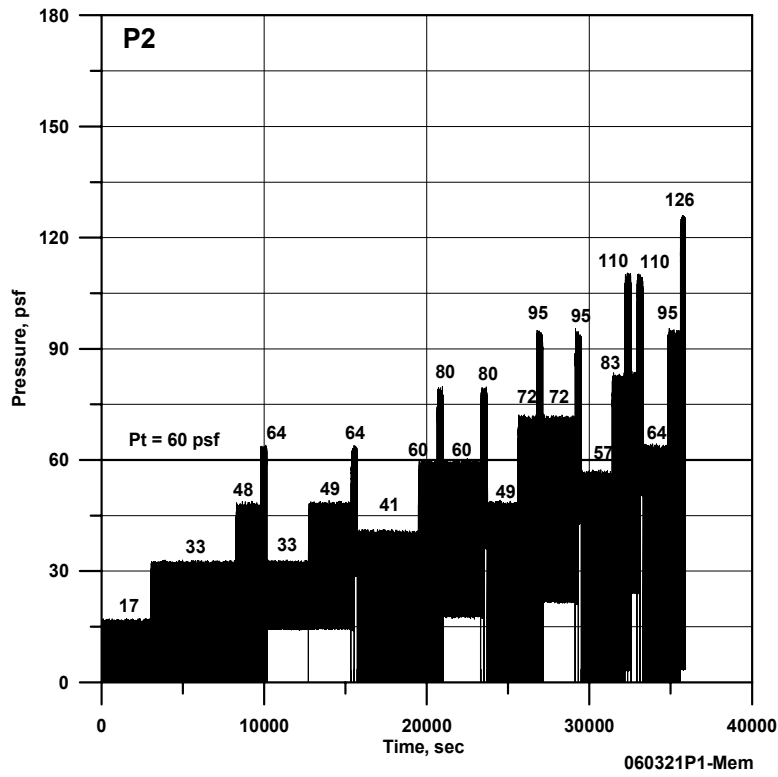
System 11- Measured Time Histories



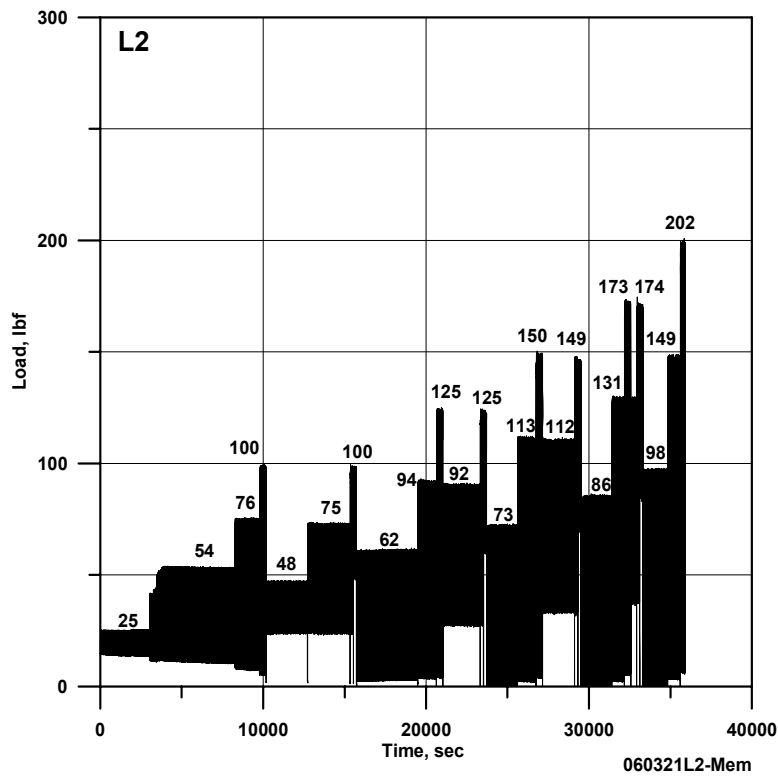
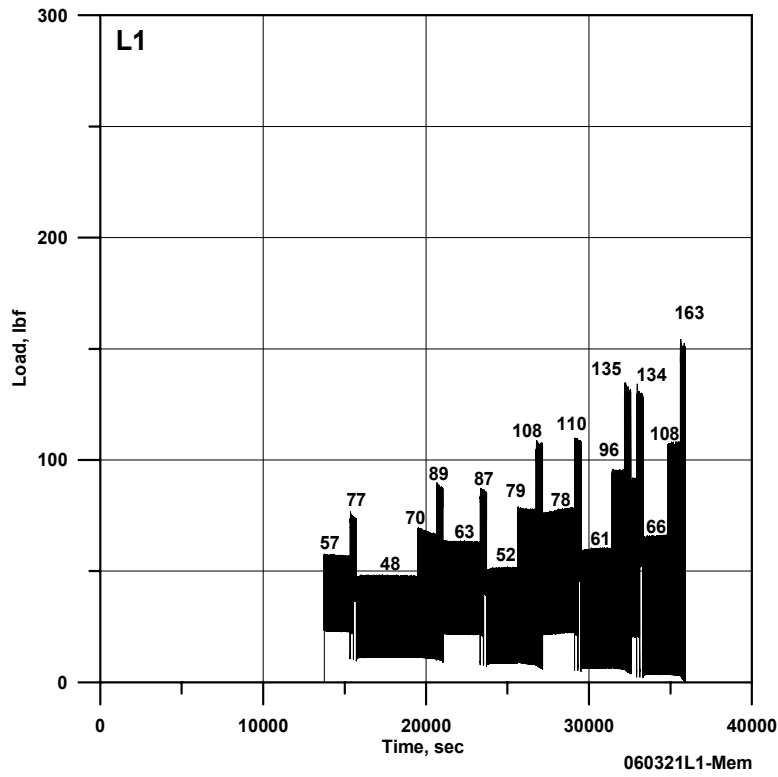
System 12- Measured Time Histories



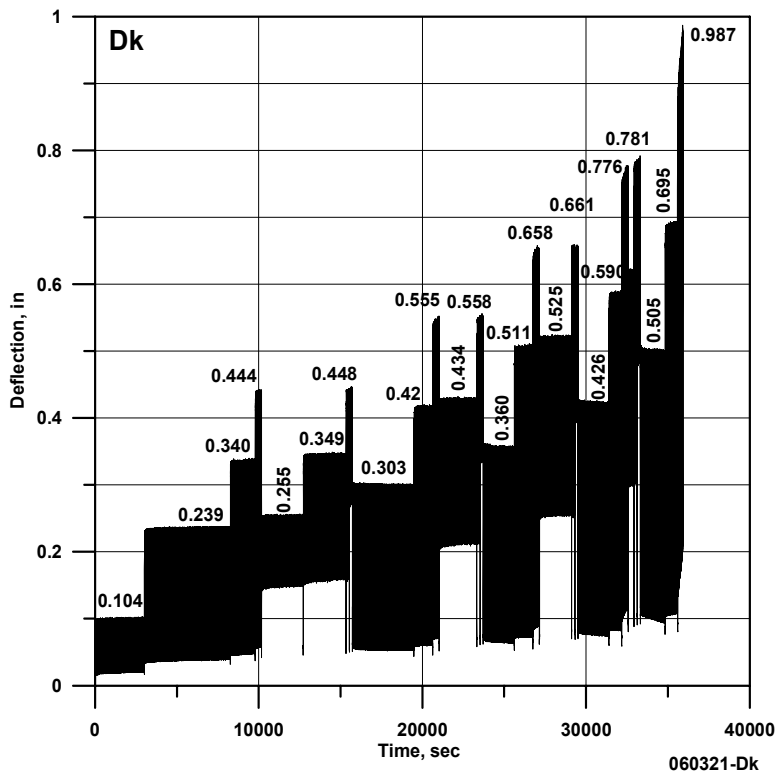
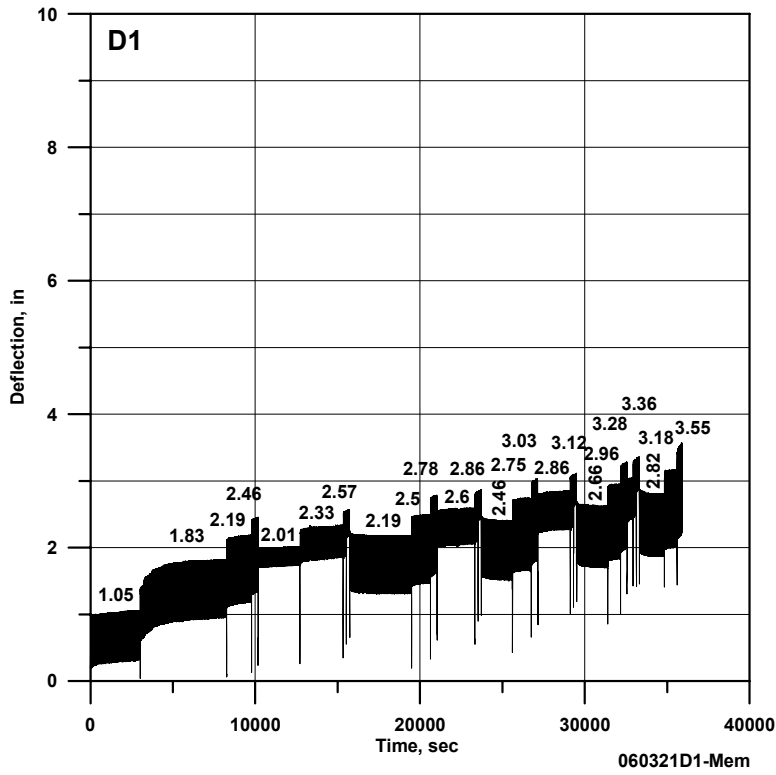
System 12- Measured Time Histories



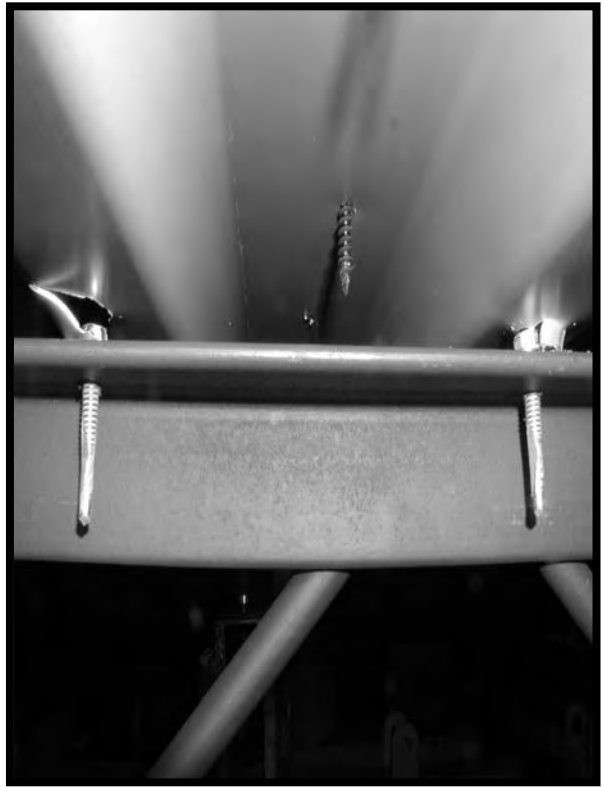
System 12- Measured Time Histories



System 12- Measured Time Histories



System 12 – Failure Mode



PART – C
Wind Uplift Resistance Data - Influence of Deck Attachment

**Table 11: Wind Uplift Resistance Data - Influence of Deck Attachment
(Imperial Units)**

System	Sustained Pressure (psf)	Sustained Load (lbf)	Membrane / Deck Deflection (in)	Failure Mode
System 13 (050305) Pt=90psf 22 Ga *(33/55 ksi), EPDM – 91", Fr/Fs = 84" / 6", Tape seam and Deck fastened over steel joists	113 N/A		N/A / 0.6	Membrane fastener pullout
System 14 (050306) Pt=90psf Same as the System 13 with spot welds over the steel joists	113 N/A		N/A / 0.4	Deck weld failed
System 15 (060323) Pt=90psf 22 Ga *(33/55 ksi), PVC 2 – 38", Fr/Fs = 32 3/4" / 6", One Sided Weld, 2 3/8" round plate, #15 Fastener and with spot welds over the steel joists	113	264 / 530**	5.8 / 0.722	Deck weld failed
System 9*** (051233) Pt=90psf 22 Ga *(33/55 ksi), PVC 2 – 38", Fr/Fs = 32 3/4" / 6", One Sided Weld, 2 3/8" round plate, and #15 Fastener	113	226 / 530**	5.92 / 0.7	Membrane seam delamination

* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

*** Please refer page 65 for components layout details

**Table 12: Wind Uplift Resistance Data - Influence of Deck Attachment
(SI Units)**

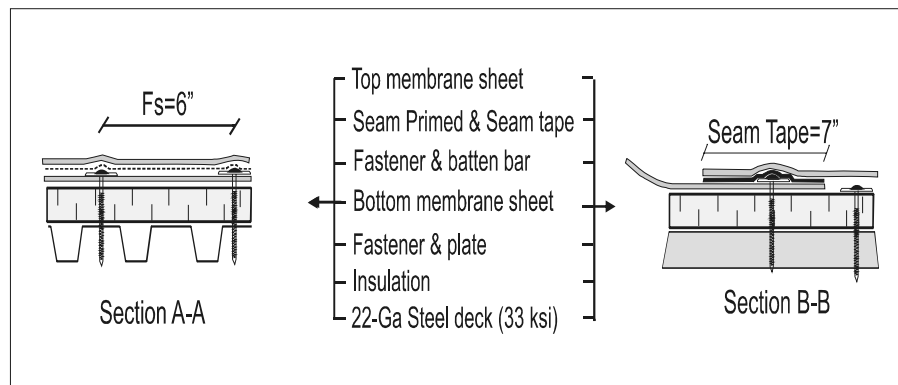
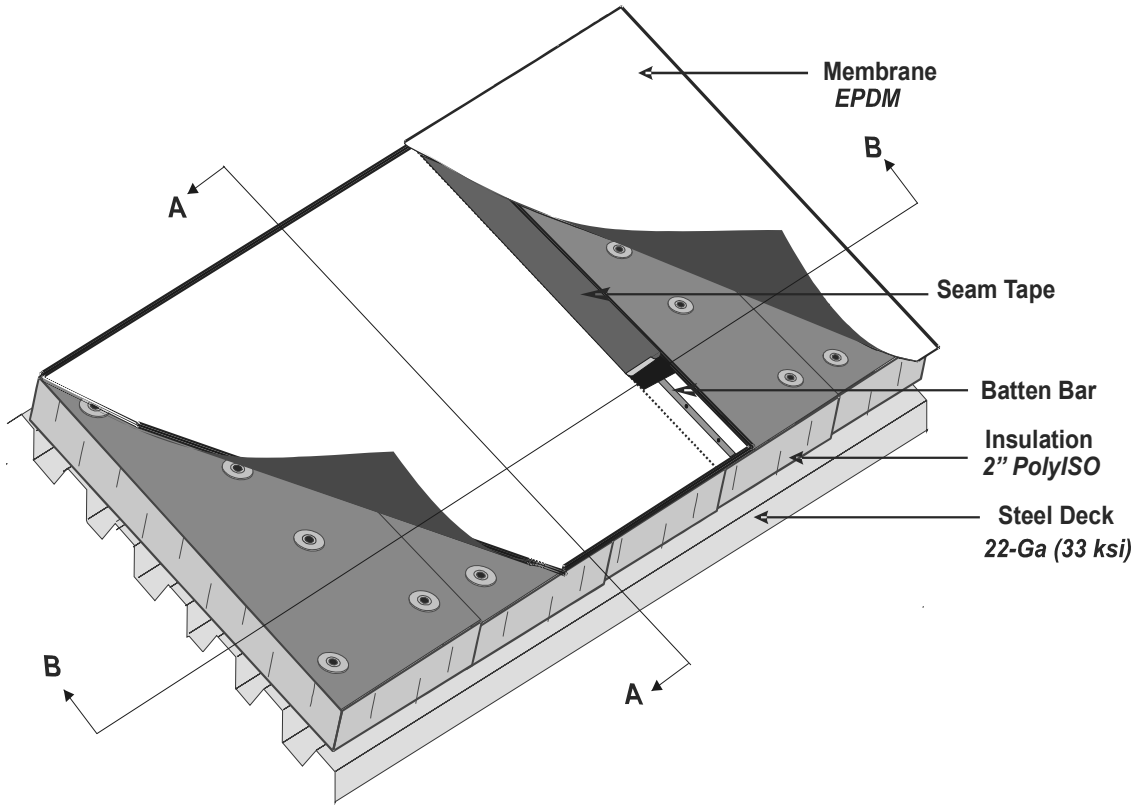
System	Sustained Pressure (Pa)	Sustained Load (N)	Membrane / Deck Deflection (mm)	Failure Mode
System 13 (050305) Pt=4309Pa 22 Ga *(230/380 Mpa), EPDM – 2311 mm, Fr/Fs = 2134/152 mm, Tape seam deck fastened over steel joists	5410 N/A		N/A / 15.24	Membrane fastener pullout
System 14 (050306) Pt=4309Pa Same as the system 13 with spot welded over the steel joists	5410 N/A		N/A / 10.16	Deck weld failed
System 15 (060323) Pt=4309Pa 22 Ga *(230/380 Mpa), PVC 2 – 965 mm, Fr/Fs = 832/152 mm, One Sided Weld, 60 mm round plate, #15 Fastener and with spot welds over the steel joists	5410	1162 / 2332**	147.32 / 18.34	Deck weld failed
System 9*** (051233) Pt=4309Pa 22 Ga *(230/380 Mpa), PVC 2 – 965 mm, Fr/Fs = 832/152 mm, One Sided Weld, 60 mm round plate, and #15 Fastener	5410	994 / 2332**	150.37 / 17.78	Membrane seam delamination

* The value before the slash is nominal tensile stress and the value after the slash is the measured tensile stress of the deck.

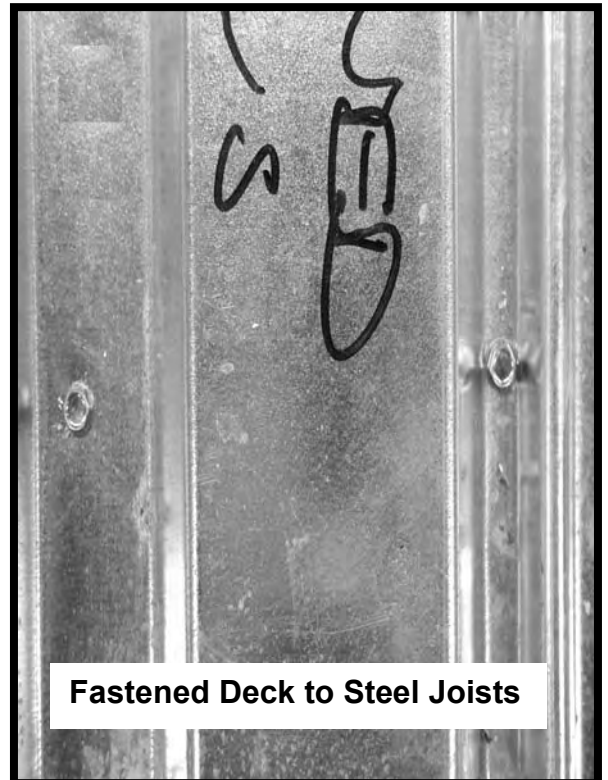
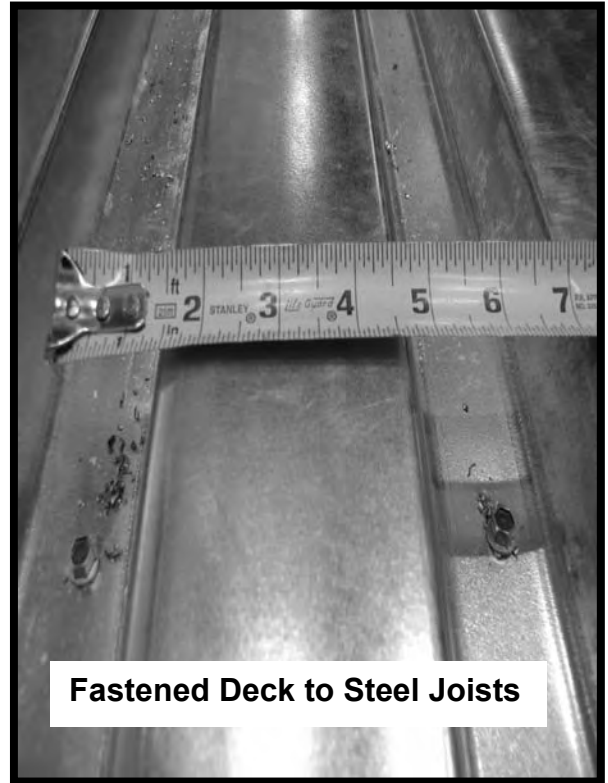
** The value before the slash is measured membrane fastener load and value after the slash is measured fastener pullout load from the deck

*** Please refer page 65 for components layout details

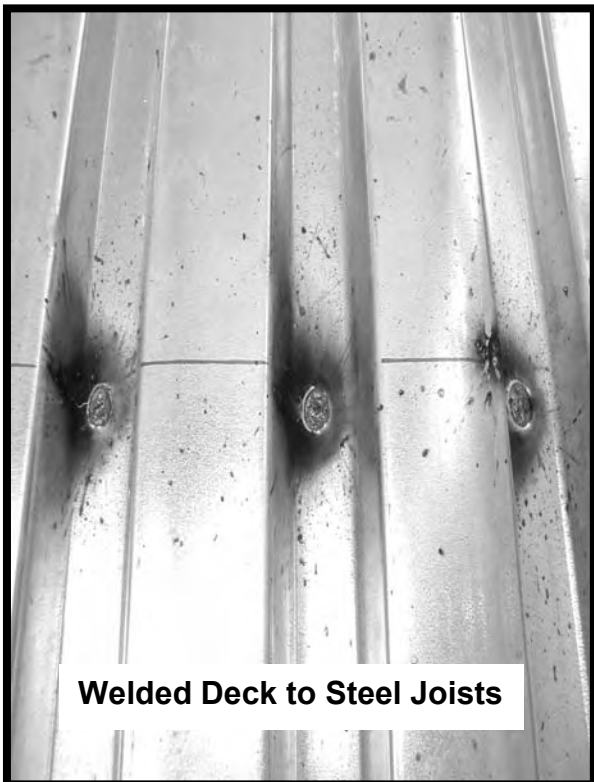
System 13 & 14– Components Layout



System 13 & 14– Installation



System 13 & 14– Installation



System 13 & 14- Installation



Table 13: Nominal physical and mechanical properties of the components for System 13 and System 14

Deck

Type	Profiled 22 gauge metal
Thickness*	22 Ga: 0.03" (0.76 mm), nominal; 0.74 mm, measured
Overall Depth	1 1/2" (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2004*	22 Ga (33 / 55 ksi) = 525lbf (2310N)
Source Vicwest	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 5 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type None	
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Membrane

Type EPDM	
Width	91" (2311 mm)
Thickness	45 mil (1.1 mm)
Tensile Property as per ASTM D 751-98* from <u>IRC-IR-807, 2000</u>	XD: Breaking strength = 1163 psi (8 MPa) XD: Elongation at break = 187% MD: Breaking strength = 1155 psi (8 MPa) MD: Elongation at break = 135%

Attachment

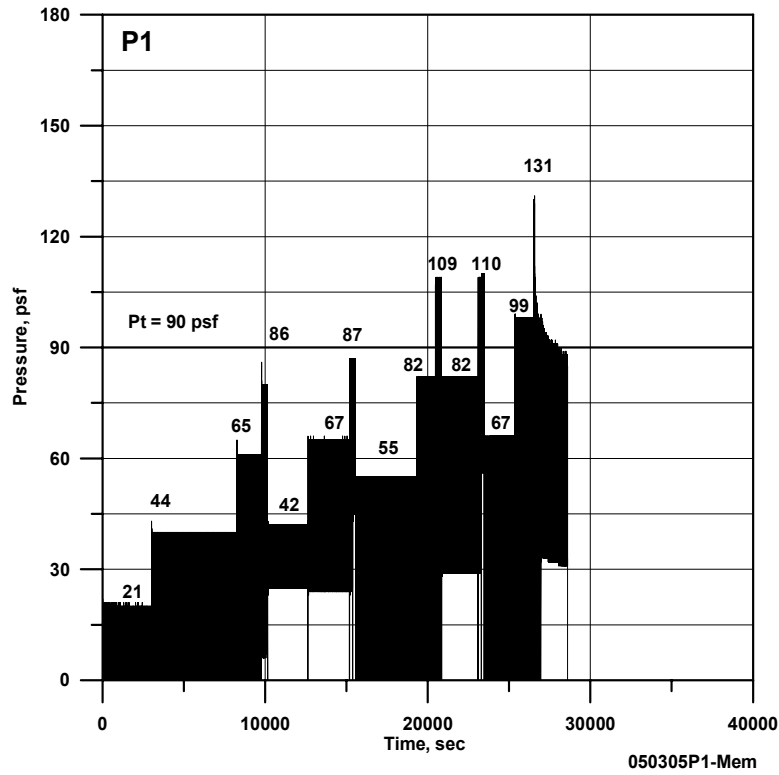
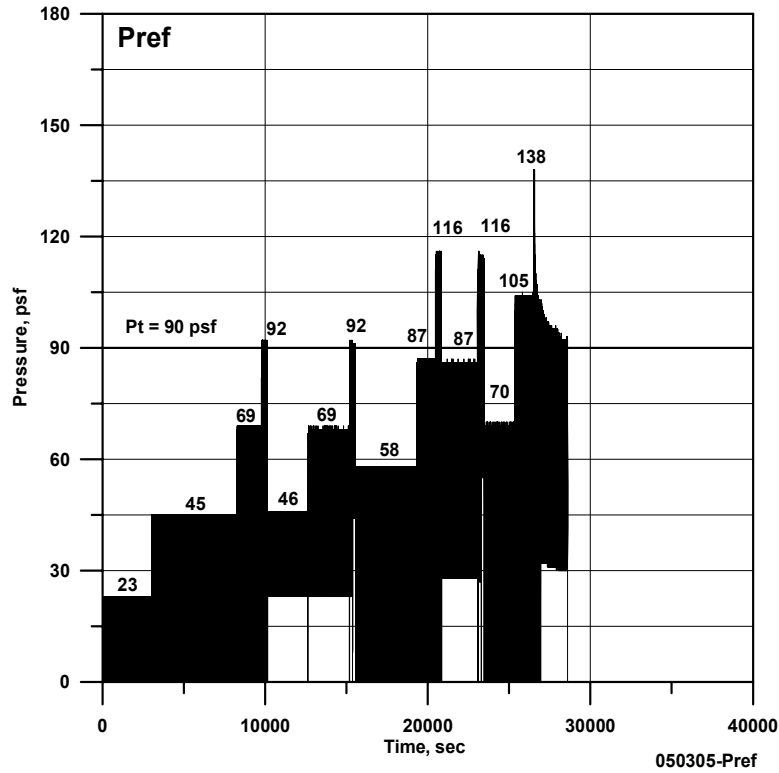
Type	Mechanical fasteners with batten
Fastener	3" (76mm), Heavy duty
Metal Batten	1" (25.4 mm) wide metal batten
Fastener Row Spacing	85" (2159 mm)
Fastener Spacing	6" (152 mm)
Slippage Control	Yes

Seam

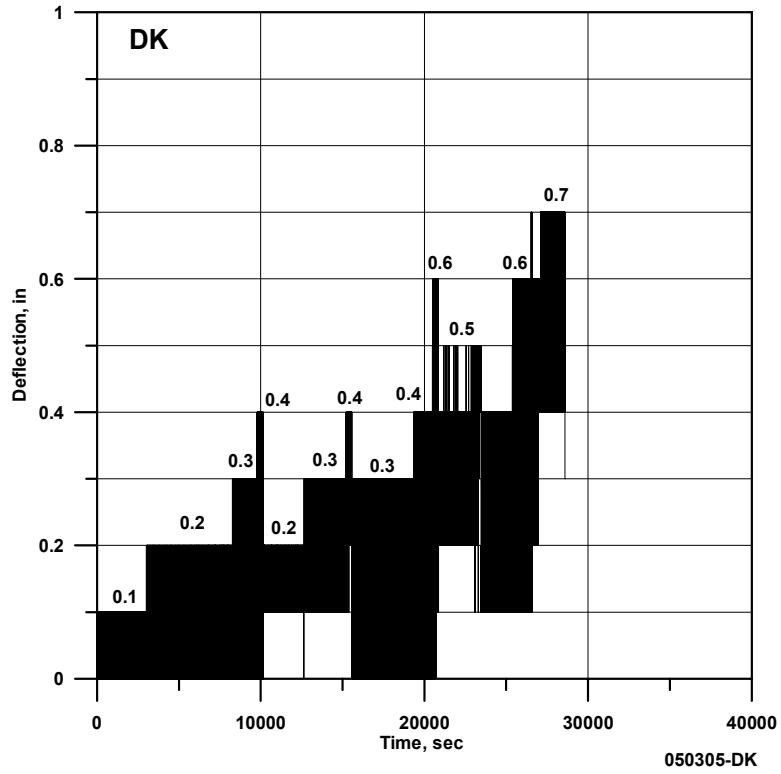
Type	Seam primed and applied with seam tape
Seaming Width	Overlap = 6" (152 mm)

* NRC Test Results

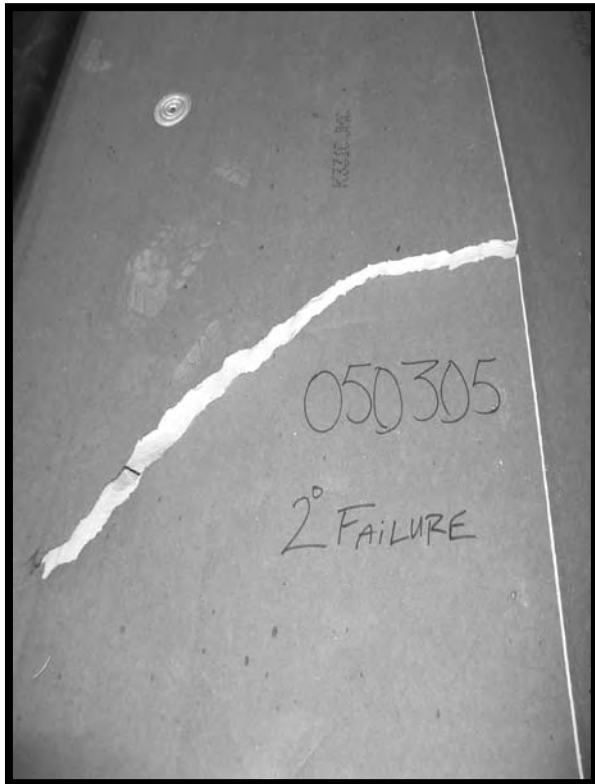
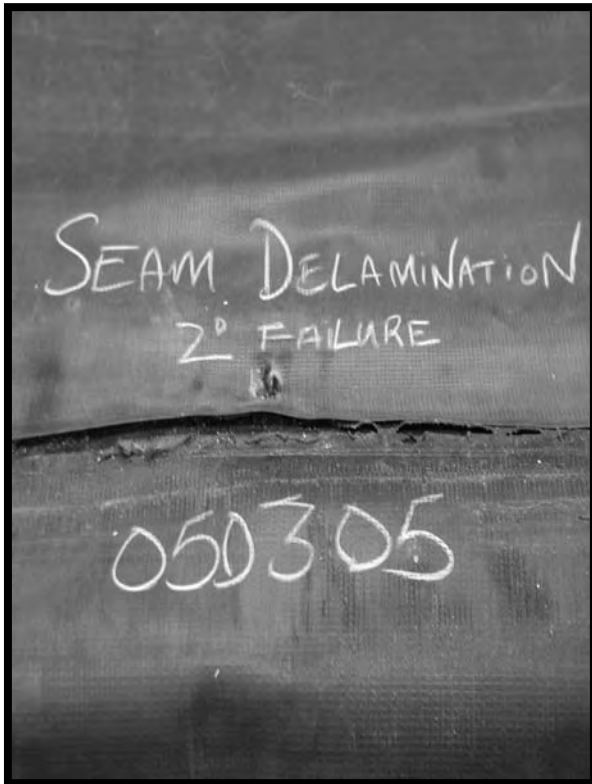
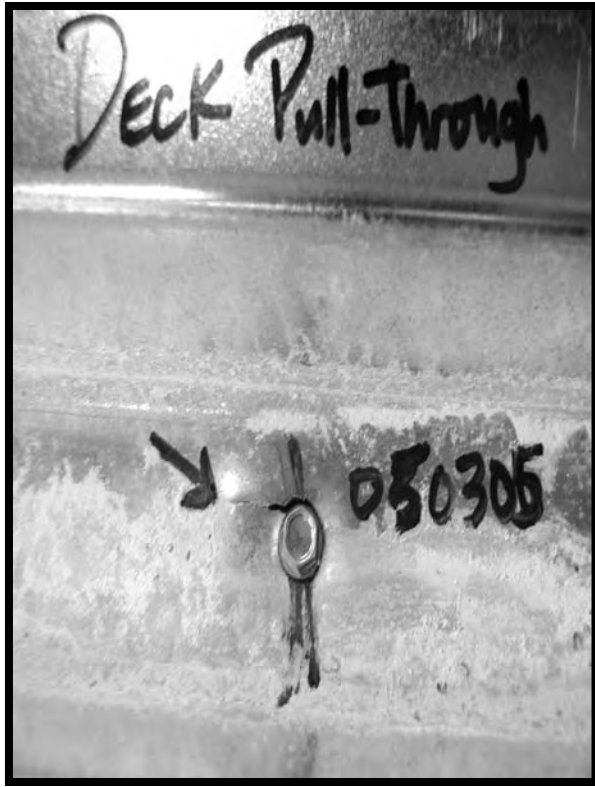
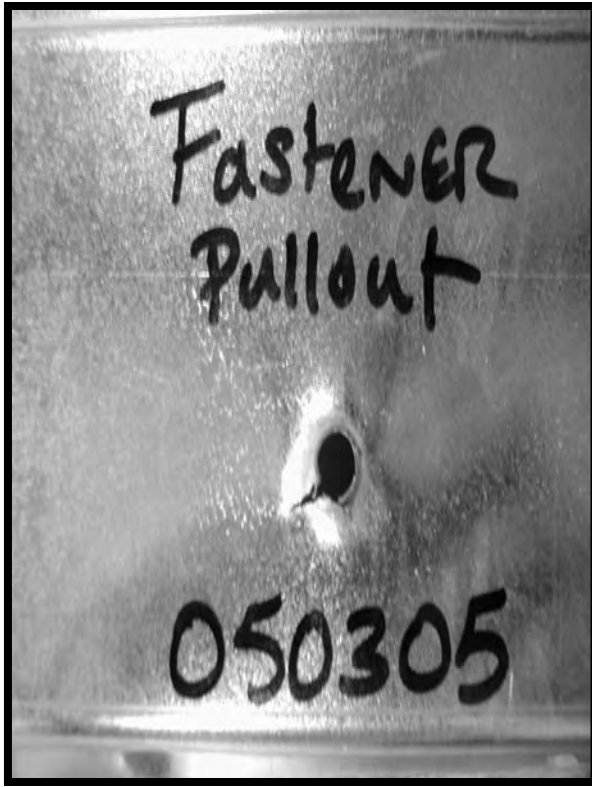
System 13- Measured Time Histories



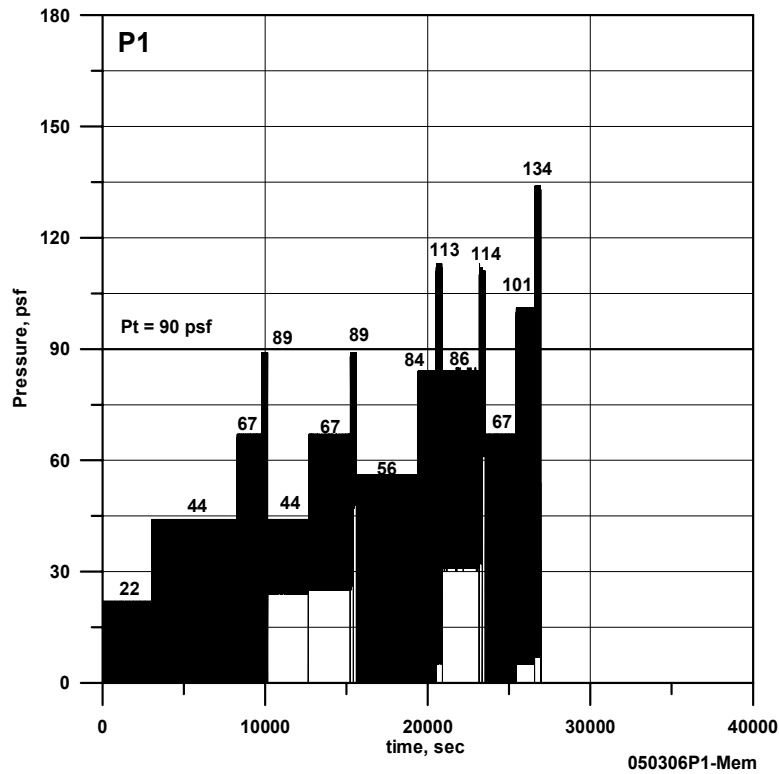
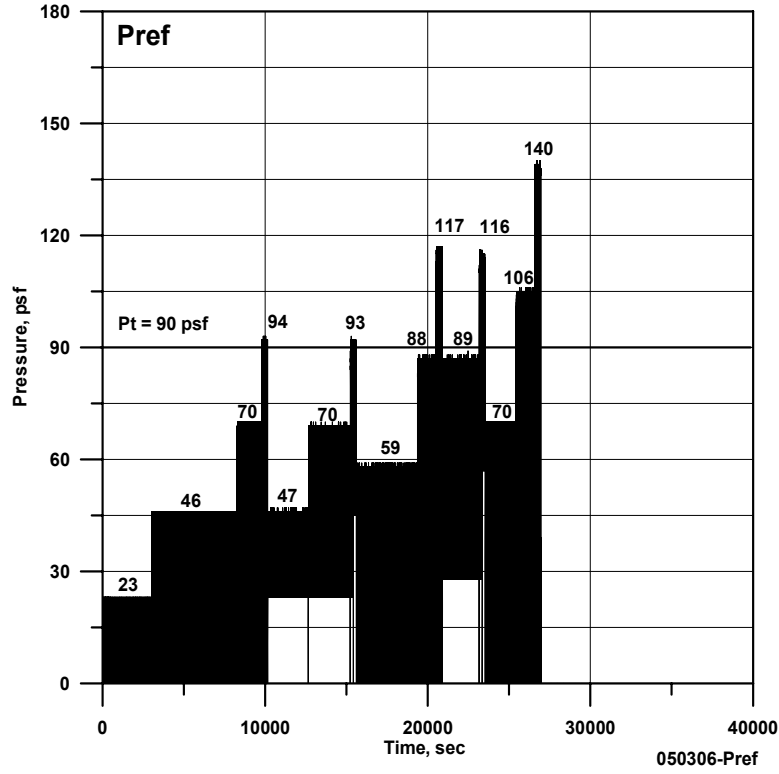
System 13- Measured Time Histories



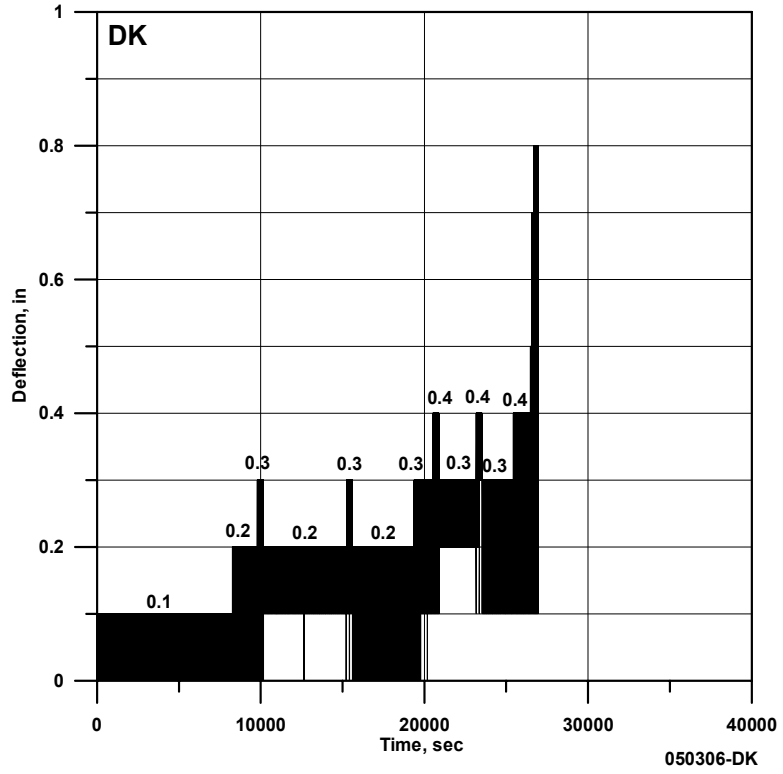
System 13 – Failure Mode



System 14- Measured Time Histories



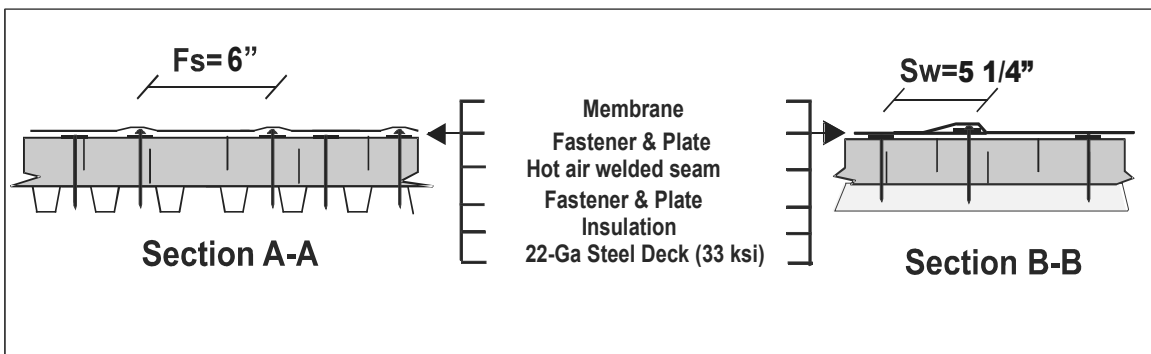
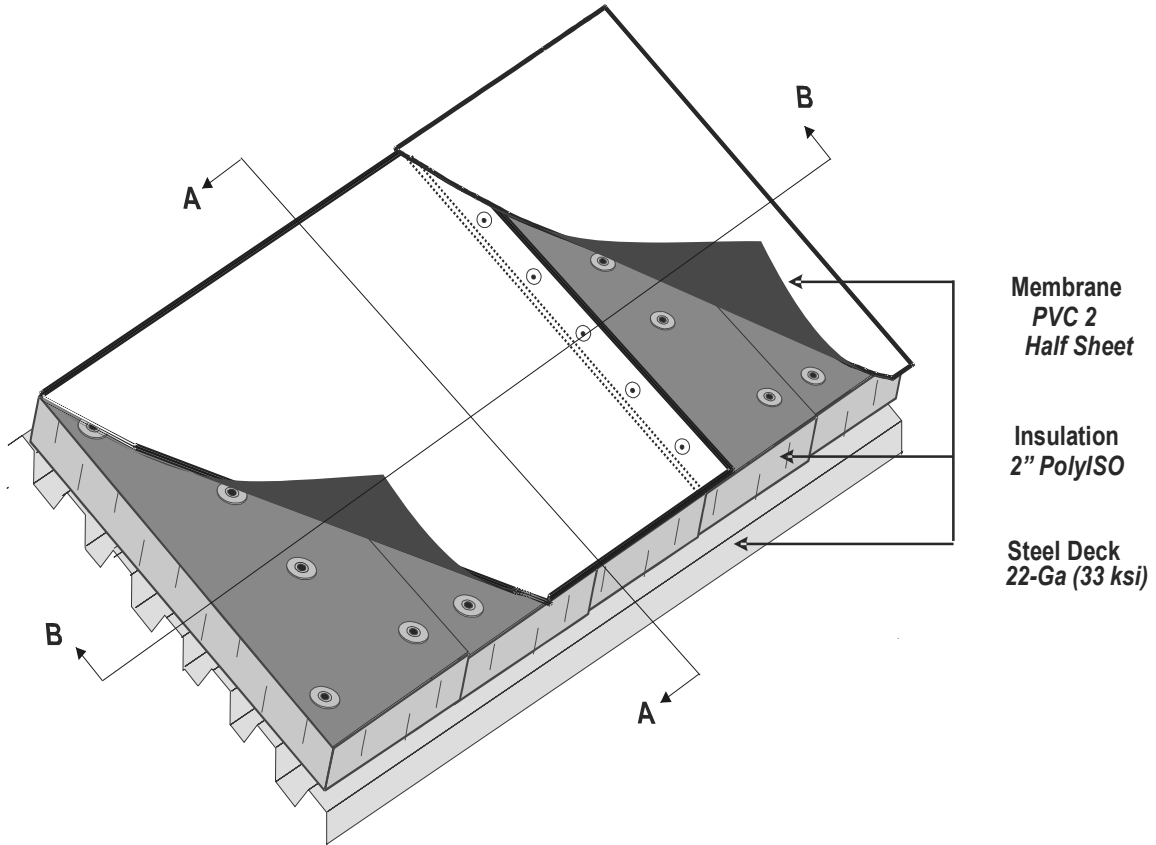
System 14- Measured Time Histories



System 14 – Failure Mode



System 15 – Components Layout



** Please refer to page 49 for instrumentation layout*

Table 15: Nominal physical and mechanical properties of the components for System 15

Deck

Type	Profiled 22 gauge metal
Thickness*	22 Ga: 0.03" (0.76 mm), nominal; 0.80 mm, measured
Overall Depth	1 1/2" (38 mm)
Flute Spacing	5 7/8" (150 mm)
Fastener Pullout as per ANSI/SPRI FX-1-2006*	22 Ga (33 / 55 ksi) = 516lbf 2296 (N)
Source CANAM	

Insulation

Type Polyiso	
Dimensions	4' x 8' (1219 mm x 2438 mm) x 2" (51 mm)
Attachment	Mechanically fastened, 5 fasteners per board
Compressive Strength as per ASTM D1621-1997	25 psi (170 kPa)
Source Johns	

Air/Vapor Barrier/Retarders/Support Board

Type None	
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Membrane

Type PVC										
Width	76" (1930 mm)									
Thickness	45 mil (1.1 mm)									
Tensile Property as per ASTM D 751-2000*	<table border="0"> <tr> <td></td> <td align="center">MD</td> <td align="center">XD</td> </tr> <tr> <td>Breaking strength, KN (lbf)</td> <td align="center">1.55 (348)</td> <td align="center">1.25 (281)</td> </tr> <tr> <td>Elongation at Max. Load, %</td> <td align="center">31.5</td> <td align="center">23.9</td> </tr> </table>		MD	XD	Breaking strength, KN (lbf)	1.55 (348)	1.25 (281)	Elongation at Max. Load, %	31.5	23.9
	MD	XD								
Breaking strength, KN (lbf)	1.55 (348)	1.25 (281)								
Elongation at Max. Load, %	31.5	23.9								

Attachment

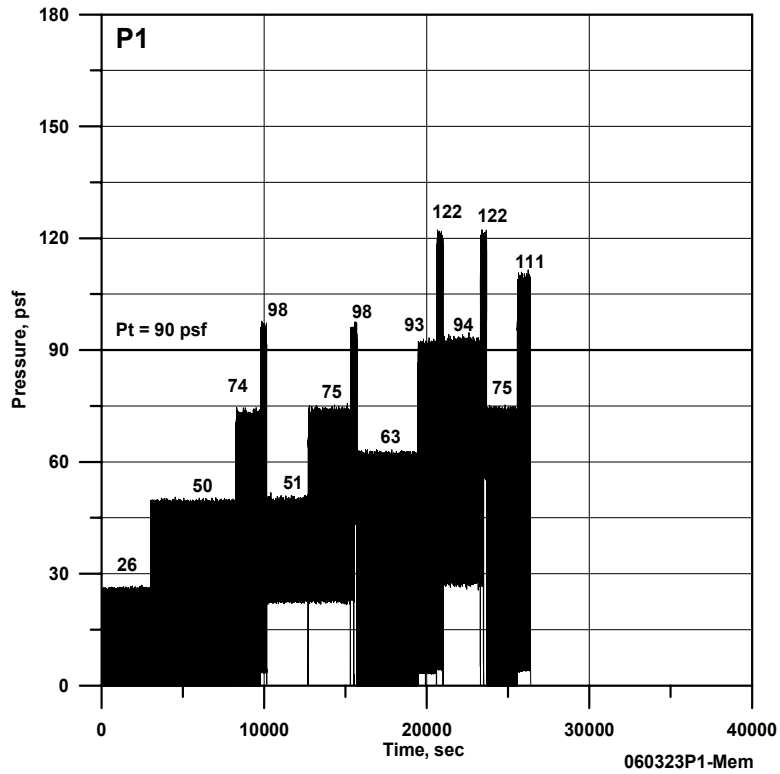
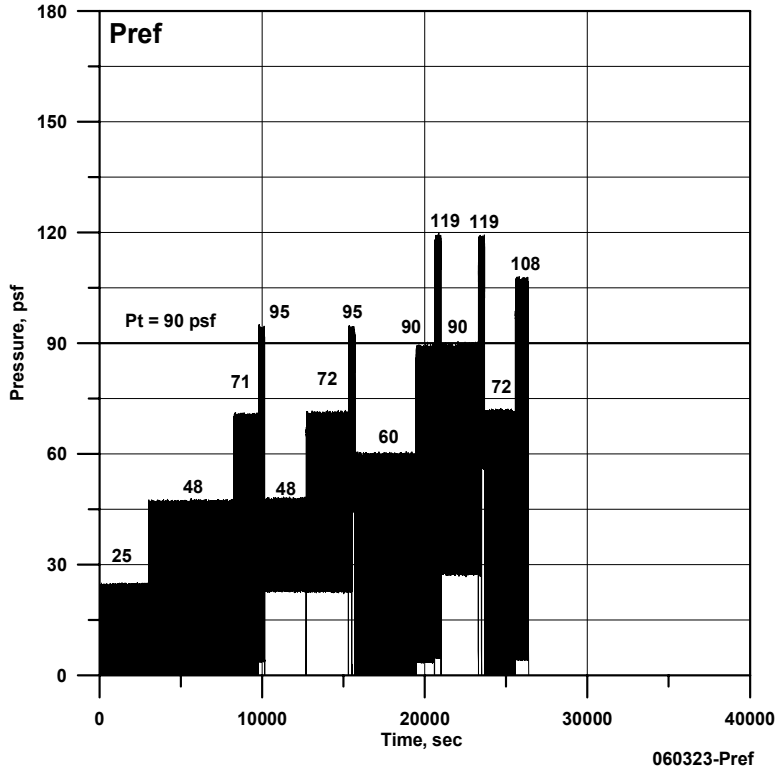
Type	Mechanical fasteners with plates
Fastener	3" (76mm), #15
Polymer Batten Bar	2 3/8" (60 mm) round plate with barb
Fastener Row Spacing	32 3/4" (832 mm)
Fastener Spacing	6" (152 mm)
Slippage Control	Yes

Seam

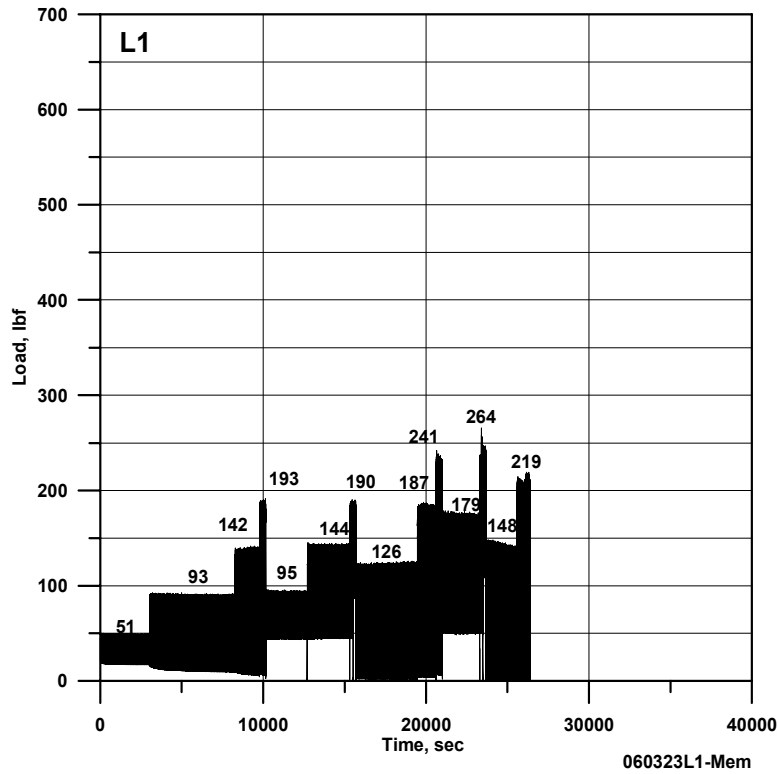
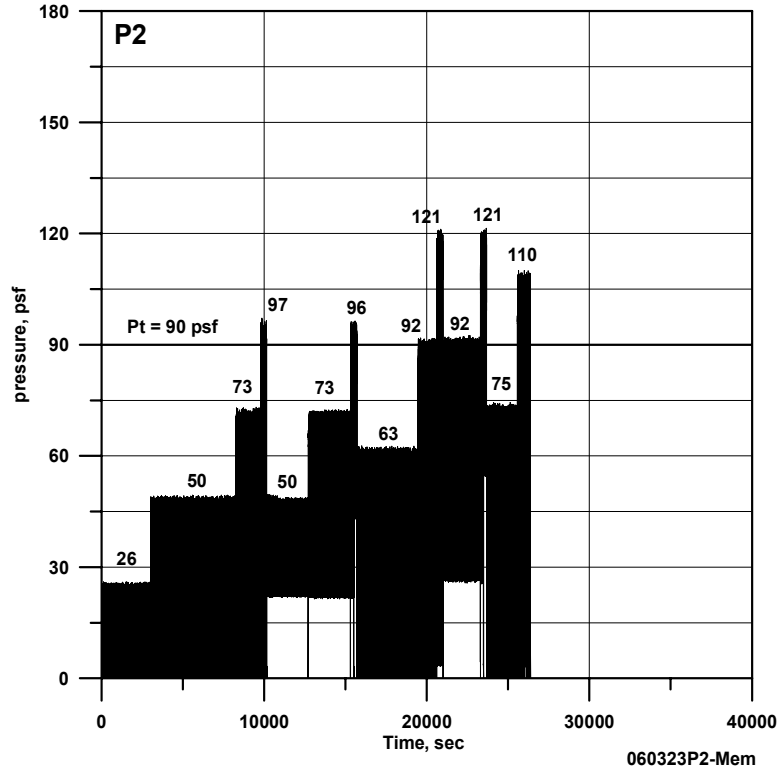
Type	Hot air welding (One side weld)
Seaming Width	Overlap = 5 1/4" (133 mm) Temperature: 540°C Speed: 3m/min

* NRC Test Results

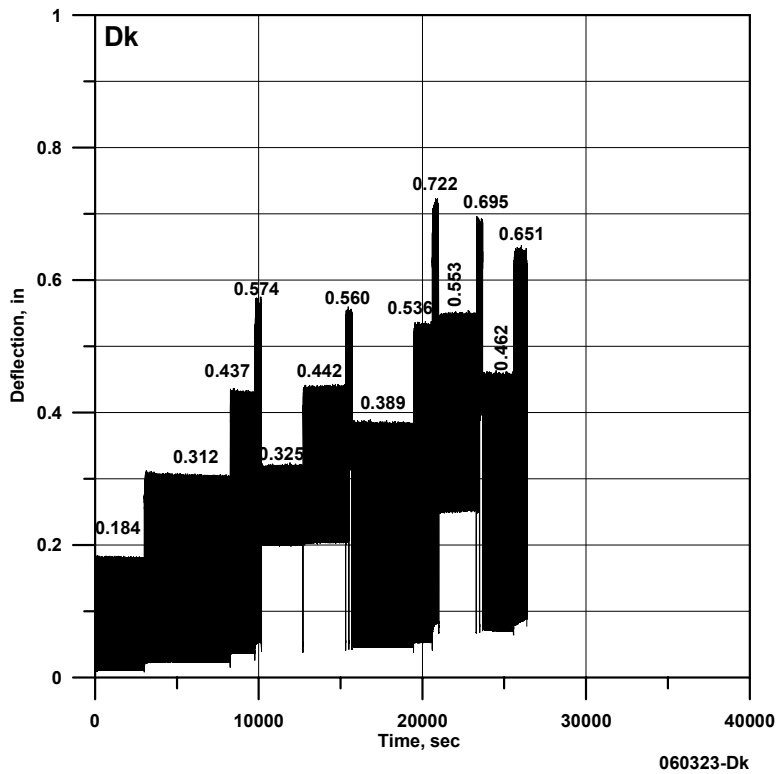
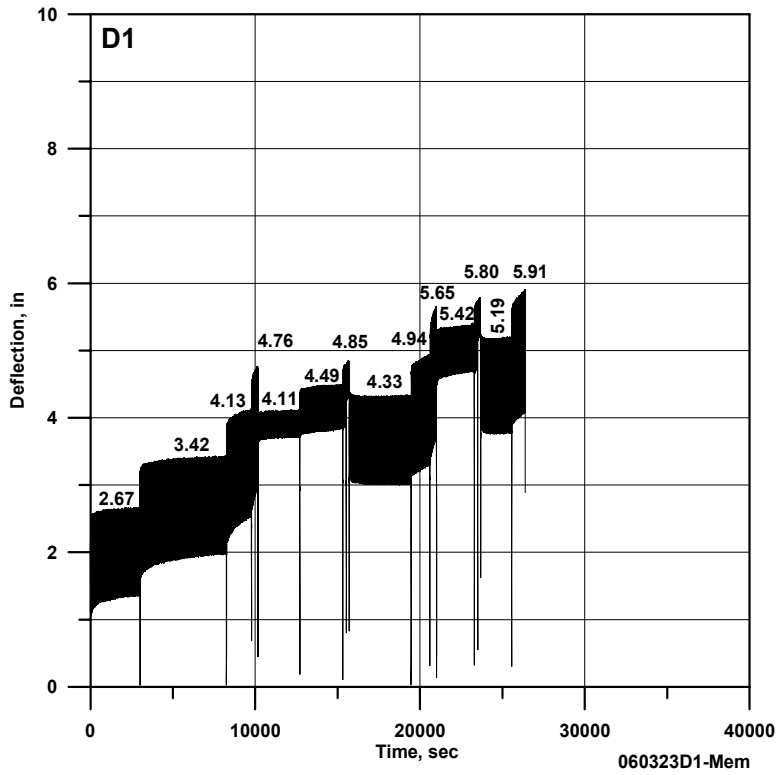
System 15- Measured Time Histories



System 15- Measured Time Histories



System 15- Measured Time Histories



System 15 – Failure Mode

