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REMOVAL and REPLACEMENT of CAST-IN-PLACE POST-TENSIONED BOX-GIRDER BRIDGE

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16. Abstract

This report describes the analytical investigation of the removal and replacement of cast-in-place, post-tensioned, box-girder bridge decks. In order to extend the life of the overall bridge, the deck typically must be replaced. This is problematic in a post-tensioned bridge where the deck is part of the structural system that resists the prestress force. This analytical investigation examines the impact of deck removal and replacement.

As bridges deteriorate due to environmental effects, this deterioration is more severe in the decks. Four specific bridges were chosen for analysis. These bridges were two simple span bridges (non-skewed and skewed), a two-span continuous bridge, and a three-span continuous bridge. The investigation was performed on bridges that might be considered for deck replacement in the future.

A 3D finite element analysis was performed on all bridges and compared with a 2D analysis. Processes and recommendations for deck removal were given for simple and continuous span bridges. The impact in the amount of skew was also investigated in this topic. Recommendations were also given for traffic analysis and future design considerations for simple and continuous span bridges.

It was found that deck removal and replacement must be considered on a case-by-case basis. If the bridge is a simple span bridge, then additional prestressing can be used to support the bridge while the deck is being replaced. The additional prestressing tendons placed on the bottom of the bridge were found to be ineffective at reducing the stress levels for the continuous structures. If the bridge is a continuous span bridge, then a 2D analysis must be performed to evaluate if shoring is necessary. Additional prestressing keeps the concrete stresses within allowable levels.

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Removal and Replacement of Cast-in-Place, Post-Tensioned, Box-Girder Bridge

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Chapter 1

Introduction

1.1 Background

One of the most popular bridges in the western states is the cast-in-place, post-tensioned, box-girder bridge system, which accounts for approximately 70 percent of the concrete bridges in the western states, mainly California, Nevada, and Arizona. Post-tensioned bridges are shallower in depth than reinforced concrete bridges while spanning the same length under the same loading conditions. Generally, the post-tensioned member depth is about 65 to 80 percent less than a typical reinforced concrete member; therefore, the post-tensioned member requires less concrete and about 20 to 35 percent of the amount of steel reinforcement.

Prestressing systems result in some added costs to the bridge. The formwork is more complex, since prestressed sections are normally composed of flanged sections with thin webs. There are also costs of prestressing the bridge, and the additional costs of hardware for construction. The initial costs of reinforced concrete bridges and prestressed bridges are usually very similar. The economic savings of a prestressed bridge is noticed in the long-term savings. Less maintenance is required on post-tensioned bridges, and a longer working life is achieved due to compression of the deck. Also, lighter foundations are achieved from a relatively lighter superstructure.

In western states, specifically north-western states, salt is extensively used to keep the roads clear during the winter. Deck deterioration is accelerated and while bridges are designed to last 50 to 75 years, bridges will often require at least one deck replacement during its design life.

During the construction of cast-in-place, post-tensioned, box-girder bridges the deck or top flange of the structure becomes an integral part of the bridge system. The deck of the bridge carries the compression force under positive dead load and live load moment. During prestressing of the system, the compression forces in the deck/top flange decrease due to the added tension in the top flange from the post-tensioning. The deck is used and needed to resist the post-tensioning force and the dead load.

This is much different than a pre-tensioned bridge, where the deck is assumed to be an additional dead load on the pre-tensioned girders. The top flange of the bridge does not receive any initial critical stresses and acts like a composite section, only under live load. Therefore, if the deck is removed, the system returns to the configuration it had in the prestress yard.

If the deck or top flange is removed after prestressing in a post-tensioned bridge, the compression block must change to account for the new cross sectional properties of the bridge. In turn, the moment of inertia, in the strong axis, decreases, as well as the eccentricity of the prestressing tendons. The change of the eccentricity of the prestressing tendon results in a change of the impact of the post-tensioning. When the new deck is added, the new concrete acts as additional dead load, and initially has no stiffness or strength. This is a significant load for the bridge to carry, especially since the top flange is gone and the eccentricity of the prestress has been altered.

1.2 Objectives

The objective of this project was to develop an economic way to remove and replace the existing deck in a post-tensioned system and, if necessary, determine how the design of new structures needs to be altered to facilitate future deck removal. The economic cost of removing and replacing the deck should be less than replacing the full structure of the bridge. This objective will be accomplished by conducting computer analyses on representative bridges. These analyses will take the bridges through the process of deck removal and replacement.

1.4 Report Layout

The following chapters will describe the process that was used to remove and replace the bridge decks from start to finish. The first step was to select potential bridges for the analyses. The narrowing of the bridges to four main types is described in Chapter 2. Chapter 2 will describe and compare 2D analysis and 3D analysis results. The results of the western states survey concerning deck replacement are also described. Chapter 3 will describe the theory and analysis used to remove and replace bridge decks in non-skewed and skewed simple span bridges. Chapter 3 will also provide two examples of bridges for which the decks have been removed. Chapter 4 will describe the deck removal and replacement of continuous span bridges, both 2-span and 3-span bridges. Chapter 5 will discuss construction and traffic implications as well as any possible design recommendations for future bridge construction. At the end of the report will be a summary of the results and their conclusions.

Chapter 2

Bridge Selection and Preliminary Analysis

2.1 General Comments

In order to investigate the removal and replacement of cast-in-place, post-tensioned, box-girder bridge decks, it was decided to select representative bridges for the analyses. Four bridges were selected that are located in the Northern Nevada area and are candidates for repair in the future.

2.2 Western DOT Survey

A survey of nine western DOTs was conducted including California, Colorado, Wyoming, Idaho, Montana, New Mexico, Washington, Texas, and Utah. A copy of the survey is included in Appendix A. The survey asked if they have ever removed, fully or partially, any cast-in-place, post-tensioned, box-girder bridge decks. Six states responded: California, Colorado, Idaho, New Mexico, Texas, and Utah. The response in all cases was that this had not been done and possibly needed to be looked into (all other questions in the survey were not answered, therefore no data was provided by the state DOTs that were surveyed).

2.3 Selection of Bridges

To establish four prototype bridges to research and analyze, a list of bridges was compiled that are located throughout northern and southern Nevada, shown in Table 2.1. Even though southern bridges do not have the same deck deterioration affects that the northern bridges have, southern bridges were used to find a more accurate representation for continuous span bridges. The four prototype bridges selected were a non-skewed simple-span bridge, a skewed simple-span bridge, a two-span continuous bridge, and a three-span continuous bridge. These four specific bridges were chosen because they represent the majority of post-tensioned bridges in Nevada. They are the most probable bridges that would require deck replacement in the future. Skewed and non-skewed bridges were selected to determine if skew has an impact. The information was then analyzed to see the distribution of bridges in different critical categories. Categories of interest were: simple or continuous span bridges, angle of skew, number of spans, span lengths, width of bridges, and year of construction. The results of the statistical distribution of categories are found in Figures 2.1 to 2.9.

Figures 2.1 and 2.2 show the distribution of bridge lengths in county groups one, two, and three. County groups two and three are bridges located in Northern Nevada, and county group one is located in Southern Nevada. Emphasis will be placed on groups two and three since they are in Northern Nevada. A majority of the simple span bridges, non-skewed and skewed, lie between 100 and 150 feet. Figure 2.3 shows the distribution of bridge widths in county groups two and three. The majority of the bridges are approximately 40 to 60 feet in width. Using these figures, Bridge G1697S was chosen to analyze for the non-skewed simple span bridge. The bridge has no skew, has a 132 foot span length, and a deck width of 53 feet. Even though the bridge was built in 1994, which lies outside the distribution shown in Figure 2.4, Bridge G1697S satisfies all other criteria for a mean standard bridge.

Figures 2.5 and 2.6 show the amount of skew in county groups one, two, and three. Using the distribution for span and width, shown in Figures 2.1, 2.2, and 2.3, and the distribution for skewed bridges shown in Figures 2.5 and 2.6, Bridge I1301E was selected for the skewed, simple span bridge. It has a span length of 180 feet, a width of 45 feet, and a 30 degree skew. Even though this bridge was built in 1996 and lies outside the normal distribution for year of construction, it is a representative bridge for deck removal in the future.

Figure 2.7 shows that most of the continuous span bridges are in the two to three span bridge range. Therefore, to properly analyze continuous span bridges, a two-span and a three-span bridge were chosen for the project. Bridge I871E was chosen for the analysis of the two-span continuous bridges. It has span lengths of 145 and 165 feet respectively, which were chosen from the criteria in Figures 2.8 and 2.9. It has a deck width of 45.5 feet, a 49 degree skew, and was built in 1977. Bridge I873 was chosen for the analysis of the three-span continuous bridges. It has span lengths of 60, 160, and 60 feet respectively, a deck width of 39 feet, a 15-degree skew, and was built in 1979. Referencing Figures 2.4 through 2.9, both bridges lie within all categories for the normal standard bridge to be analyzed.

2.4 Specifications of Four Bridges

Details of the four bridges are given in the following section. The data was received from the Nevada Department of Transportation (NDOT).

Bridge G1697S
(See Figure 2.10 for typical section and prestressing diagram)
Span Length = 132 feet
Width = 53 feet
Skew = 0 degrees
f'_c (@ 28 days) = 4,550 psi
E_c = 3,865 ksi
P_j = 12,812 kips
Losses = 32 ksi

Bridge I1301E
(See Figure 2.11 for typical section and prestressing diagram)
Span Length = 180 feet
Width = 45 feet
Skew = 30 degrees
f'_c (@ 28 days) = 5,275 psi
E_c = 4,075 ksi
P_j = 15,256 kips
Losses = 33 ksi

Bridge I871E
(See Figure 2.12 for typical section and prestressing diagram)
Span Length = 145 feet and 165 feet
Width = 45.5 feet
Skew = 49 degrees
f'_c (@ 28 days) = 4,400 psi
E_c = 3,780 ksi
P_j = 15,754 kips
Losses = 32 ksi

Bridge I873
(See Figure 2.13 for typical section and prestressing diagram)
Span Length = 60 feet, 160 feet, and 60 feet
Width = 39.5 feet
Skew = 15 degree
f'_c (@ 28 days) = 4,500 psi
E_c = 3,824 ksi
P_j = 10,151 kips
Losses = 32 ksi

2.5 Analysis Methods

The majority of the bridge analyses performed as part of this project were done with SAP 2000. SAP 2000 is a static, three dimensional, finite element program. SAP 2000 has many other capabilities, such as dynamic loading and nonlinear analysis. The static analysis served the purpose of this project.

The main structure of the bridges was modeled using shell elements, which include: girders, sofit, deck, abutments, piers, and diaphragms. The shell element is a three or four node shape that combines separate membrane and plate bending behaviors. SAP 2000 allows three possible choices in formulating the shell elements: pure membrane behavior, pure plate behavior, or full shell behavior. All shell elements in the bridges were modeled using the full shell element - all forces and moments can be supported by the element. Besides selecting the material properties of the shell element, the thickness formulation must also be selected. For diaphragms, abutments and piers a thicktype shell element was selected. Thicktype shell elements include the effects of transverse shear deformation. Girders, sofits, and the deck were modeled using a thintype shell element, which neglects transverse shearing deformation. Figures 2.14 through 2.21 shows the shell element and tendon layout for all the analyzed bridges.

Prestressing tendons in the system were modeled using frame elements. The frame elements had solid circular section properties, and then, by using the prestressing option in SAP 2000, a specified tension was added to each individual frame element. Finally, material properties were assigned to the frame and shell elements. Support conditions were also assigned. The material properties were chosen from the actual properties of the bridge.

For the 3D finite element analysis for simple span bridges and continuous span bridges, references are made in relation to different construction phases in the analysis process. Each stage represents a critical point in construction ranging from Stage 1, which is the removal of the deck, to Stage 4, which is the final point in construction (the bridge is able to be in use).

Stage 1 represents the first critical point in construction when the deck has been removed. Figure 2.22 shows what this stage would typically look like in the finite element analysis when the deck has been removed and the interior girders have been exposed. Stage 2 is when techniques will be used to reduce the impact of deck removal. Figure 2.23 shows Stage 3, the next stage in construction when the deck has been poured but is not accounted in the stiffness of the bridge. For Stage 3, an additional dead load has been added to each girder of the bridge simulating a "wet and soggy" deck. Figure 2.24 shows the typical full deck case in the finite element analysis. The figure is the outline of the bridge including the deck. In Stage 4, the full deck is analyzed with the methods used in Stage 2 without dead load and without the original prestress. Stage 4 uses the theory of superposition to achieve final results. These stresses from Stage 4 would then be subtracted from the stresses obtained in Stage 3, modeling the impact of removing the method used in Stage 2. This final stress state would be the stresses at the final stage in construction. These stages will be used in Chapters 3 and 4 to model deck removal specifically for simple span bridges and then multiple span bridges respectively.

To verify that the 3D analysis was accurate, some 2D modeling was conducted. This was done with a program called BDS (Bridge Design System) release 4.2. The 3D / 2D analyses are compared separately in Chapter 3 for simple span bridges, and Chapter 4 for continuous span bridges. The BDS program uses Newton's numerical integration with increments set at 1/40 of the span length to produce member properties and fixed end moments. The stiffness method is used to develop distribution factors. The Hardy-Cross method of moment distribution is used to solve the simultaneous equations. The moment distribution analysis technique considers the frame members to be linearly elastic.

Table 2.1: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
2	B1408	WALKER RIVER	FAU 340	0	505	1	402	402	8	1974
2	B1490	TRUCKEE RIVER	OLD SR 45	20	505	3	213	151	7	1976
2	B1508	HUMBOLT RIVER	IRISH AMERICAN RD	35	505	2	213	98	7	1986
2	B1519	WALKER RIVER	MILLER LANE	30	505	1	351	107	7	1976
2	B1619	HUMBOLT RIVER	DUNCAN ROAD	10	505	1	305	94	9	1996
2	B1534	TRUCKEE RIVER	FAU668	99	505	3	427	189	7	1971
2	G751	SPRR	FR 409	30	505	2	210	94	7	1962
2	G1276	FAU 647, TRUCKEE R, SPRR	FAU 663	0	505	14	686	259	7	1991
2	G1504	FAU 649	SPRR	30	505	3	171	104	7	1996
2	G1697N	UPRR	US 395	0	505	1	402	162	7	1981
2	G1697S	UPRR	US 395	0	505	1	393	162	7	1981
2	H850E	CROSS ROAD	I 80	24	505	1	128	137	8	1974
2	H850W	CROSS ROAD	I 80	24	505	1	128	137	8	1974
2	H1247	FAU 655	I 580	12	505	1	360	370	7	1980
2	H1251	FAU 652	I 580	12	505	1	351	416	7	1977
2	H1553	FAU 651	CROSS ROAD	0	505	1	536	195	8	1977
2	H2008	OLD VIRGINIA ROAD	I 580	51	505	1	271	405	8	1995
2	I750	I 80	LOCKWOOD DRIVE	30	505	2	210	94	6	1962
2	I852E	FAS 398	I 80	0	505	1	335	139	6	1983
2	I852W	FAS 398	I 80	0	505	1	335	139	6	1983
2	I1248	FAU 654	I 580	7	505	1	427	370	6	1980
2	I1289N	FR 426	US 395	6	505	1	427	134	6	1974
2	I1289S	FR 426	US 395	6	505	1	427	134	6	1974
2	I1301E	FAU 651	I 80	30	505	1	549	137	7	1977
2	I1301W	FAU 651	I 80	30	505	1	549	137	7	1977
2	I1305	US 395	FAU 650	25	505	2	293	294	6	1971
2	I1306	US 395	FAU 667	20	505	2	293	154	6	1971
2	I1749N	GOLDEN VALLEY ROAD	US 395	33	505	1	472	137	7	1988
2	I1749S	GOLDEN VALLEY ROAD	US 395	30	505	1	472	137	7	1988
2	I1770N	LEMMON DRIVE	US 395	7	505	1	460	137	7	1986
2	I1770S	LEMMON DRIVE	US 395	7	505	1	460	137	7	1986
2	I1951	ZOLEZZI LANE	I 580	20	505	1	655	442	8	1995
2	I2007	OLD VIRGINIA ROAD	I 580	47	505	1	311	168	8	1995
2	I2009	OLD VIRGINIA ROAD	I 580	52	505	1	268	94	8	1995
2	B16	TRUCKEE RIVER	FAS 427	0	605	2	408	157	8	1993
2	G1748N	UPRR	US 395	47	605	3	250	199	7	1988
2	G1748S	UPRR	US 395	40	605	3	223	174	7	1988
2	I1261	US 395	CROSS ROAD	9	605	2	354	94	7	1968

Table 2.1 con't: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
2	I1949	FAS 431 MT. ROSE HWY	I 580	43	605	2	585	258	8	1995
2	I1950	SR 430 VIRGINIA STREET	I 580	20	605	2	427	433	8	1995
2	G1129	FAU651	UPPR	99	605	4	320	82	7	1996
2	I1952	SOUTH MEADOWS PKW	I 580	41	605	2	466	369	8	1995
2	B1533	TRUCKEE RIVER	FAU 662	0	605	3	195	226	8	1998
2	G1474	I 80	SPRR	99	605	3	460	N/A	7	1977
2	I1772	TERMINAL WAY	I 580 RAMP	0	605	9	402	90	7	1988
3	B894E	MAGGIE CREEK	I 80	0	505	1	253	140	7	1976
3	B894W	MAGGIE CREEK	I 80	0	505	1	253	140	7	1976
3	B895E	SUSIE CREEK	I 80	0	505	1	253	140	7	1976
3	B895W	SUSIE CREEK	I 80	0	505	1	253	140	7	1976
3	B1119	HUMBOLT RIVER	FAS 229	0	505	3	104	113	8	1965
3	B1120	HUMBOLT RIVER	FAS 229	0	505	3	104	113	8	1965
3	B1267	HENDRICKS CREEK	FAS 225	0	505	1	287	101	7	1968
3	B1657	HUMBOLT RIVER	REINHART LANE	0	505	1	335	107	7	1988
3	B1842	OWYHEE RIVER	WOLDHORSE CROSSING	0	505	1	119	49	8	1986
3	H1485E	FAU 548	I 80	10	505	1	381	137	8	1976
3	H1485W	FAU 548	I 80	10	505	1	381	137	7	1976
3	H1512E	SHOSHONE STREET	I 80	0	505	1	366	139	7	1977
3	H1512W	SHOSHONE STREET	I 80	0	505	1	366	139	8	1977
3	I891E	CROSS ROAD	I 80	0	505	1	378	140	6	1976
3	I891W	CROSS ROAD	I 80	0	505	1	378	140	6	1976
3	I900E	FAS 222	I 80	20	505	1	415	139	7	1976
3	I900W	FAS 222	I 80	20	505	1	415	139	8	1976
3	I906E	FAU 535	I 80	0	505	1	314	139	8	1977
3	I906W	FAU 535	I 80	0	505	1	314	137	8	1977
3	I920E	FAS 223	I 80	10	505	1	479	139	6	1977
3	I920W	FAS 223	I 80	10	505	1	479	139	7	1977
3	I921E	US 93	I 80	0	505	1	454	139	7	1977
3	I921W	US 93	I 80	0	505	1	454	139	8	1977
3	I932E	US 93A	I 80	11	505	1	415	137	7	1977
3	I932W	US 93A	I 80	14	505	1	415	137	7	1977
3	I1511E	ALAZON ROAD	I 80	0	505	1	314	139	7	1977
3	1511W	ALAZON ROAD	I 80	0	505	1	314	139	7	1977
3	B455	HUMBOLT RIVER	SR 789	0	605	2	229	119	8	1992
3	B1526	HUMBOLT RIVER	FAU 542	99	605	3	335	174	6	1979
3	G1414	WATER ST SP&UPPR&HUMBLT R	FAU 537	0	605	4	351	195	6	1980
3	H869E	US 95	I 80	0	605	9	305	139	7	1977

Table 2.1: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
3	H869W	US 95	I 80	0	605	9	305	139	7	1977
3	H1205	I 80	CROSS ROAD	0	605	2	396	106	7	1976
3	I871E	SR 788	I 80	49	605	2	509	139	7	1977
3	I871W	SR 788	I 80	49	605	2	506	139	8	1977
3	I873	I 80	CROSS ROAD	15	605	3	488	120	7	1979
3	I878	I 80	FAS 304	24	605	2	488	173	6	1976
3	I879	I 80	FAS 305	0	605	2	439	154	7	1976
3	I882	I 80	FAS 304	62	605	2	488	169	7	1976
3	I896	I 80	COUNTY ROAD	0	605	2	418	120	7	1976
1	B1448	FLAMINGO WASH	I 515	64	505	1	439	443	7	1996
1	B1445	DUCK CREEK	US 395	56	505	1	475	369	8	1996
1	B1540E	DUCK CREEK	FAU 594	0	505	1	335	134	7	1996
1	B1540W	DUCK CREEK	FAU 594	0	505	1	335	134	7	1996
1	B1807	REESE RIVER	IRR MOHAWK CAN RD	0	505	1	140	85	7	1996
1	G779N	UPRR	I 15	15	505	3	158	131	7	1996
1	G779S	UPRR	I 15	15	505	3	158	181	7	1996
1	G1127	UPRR	FAU 574	30	505	1	209	487	4	1996
1	G1463	UPRR, ACCESS RD. & DITCH	US 95	15	505	1	3299	442	7	1996
1	G1465	UPRR	US 95	0	505	1	338	369	8	1996
1	G1470	UPRR	US 95	35	505	1	372	369	8	1996
1	G2149	OGDEN AVENUE	UPRR	0	505	2	122	951	8	1995
1	H1211	US 95	WASHINGTON AVENUE	0	505	2	396	124	7	1994
1	H1243	US 95	TORREY PINES DRIVE	0	505	1	375	204	7	1994
1	H1412	PECOS DRIVE	I 515	20	505	1	491	370	7	1994
1	H1441	28TH STREET	I 515	2	505	1	305	442	7	1996
1	H1442	MOHAVE ROAD	I 515	2	505	1	472	372	7	1996
1	H1445	WYOMING AVENUE	I 515	0	505	1	439	480	8	1996
1	H1451	TWAIN AVENUE	US 95	11	505	1	463	443	6	1996
1	H1454	FAU 611/MOUNTAIN VISTA	3US 95	38	505	1	533	369	7	1996
1	H1457	VIKING ROAD	US 95	0	505	1	418	533	7	1996
1	H1458	GREENWAY DRIVE	US 95	18	505	1	457	369	8	1996
1	H1744	INDUSTRIAL ROAD	FAU 592	8	505	1	482	434	7	1996
1	H1836	WARM SPRINGS	US 95	23	505	1	524	369	8	1996
1	H1901N	INDUSTRIAL ROAD	I 15	35	505	1	622	259	8	1996
1	H1901S	INDUSTRIAL ROAD	I 15	35	505	1	622	265	8	1996
1	H1941	INDUSTRIAL ROAD	FAU 594	11	505	1	530	384	8	1994
1	H1971N	ROBINDALE ROAD	I 215 BELT WAY	22	505	1	527	229	8	1994
1	H1971S	ROBINDALE ROAD	I 215 BELT WAY	22	505	1	497	192	9	1995

Table 2.1 con't: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
1	H2011	I 15	FAU 590 DESERT INN	32	505	3	588	344	8	1994
1	H2032N	FOOTHILLS DRIVE	US 95	0	505	1	533	131	8	1994
1	H2032S	FOOTHILLS DRIVE	US 95	0	505	1	533	131	8	1994
1	H2040N	PARADISE ROAD	I 215 BELT WAY	51	505	1	576	229	7	1994
1	H2040S	PARADISE ROAD	I 215 BELT WAY	47	505	1	549	229	7	1995
1	I944	FAU 599	US 95	24	505	1	305	312	7	1996
1	I9453	FAU 600	US 95	11	505	1	390	280	7	1996
1	I956	I 15	FAU 573	45	505	2	396	342	6	1996
1	I1453	FAU 593	US 95	15	505	1	530	369	8	1996
1	I1459	SUNSET ROAD	US 95	26	505	1	564	369	7	1996
1	I1464	LAKE MEAD DRIVE	US 95	33	505	2	387	369	8	1996
1	I1466	US 95	HAORIZON DRIVE	0	505	2	381	311	8	1996
1	I1469	COLLEGE DRIVE	US 95	0	505	1	533	369	7	1996
1	I1471	US 95	WAGONWHEEL DRIVE	0	505	2	360	265	8	1994
1	I1505N	US 95	US 93	0	505	1	457	139	7	1994
1	I1505S	US 95	US 93	0	505	1	457	139	7	1994
1	I1843E	HUSITE PARKWAY	RAMP R-17	15	505	1	320	94	8	1996
1	I1844W	RAMP R17	HUSITE PARKWAY	35	505	1	351	125	8	1996
1	I1899	US 95 OFF RAMP	FAU 582 SOUTHBOUND	63	505	1	375	131	8	1996
1	I1972N	WARM SPRINGS ROAD	I 215	31	505	1	588	230	7	1996
1	I1972R	PARADISE ROAD	RAMP	15	505	1	524	131	8	1996
1	I1972S	WARM SPRINGS ROAD	I 215	31	505	1	585	230	7	1996
1	I1985N	RAMP R9	I 15	24	505	1	219	222	8	1996
1	I1985S	RAMP R9	I 15	24	505	1	219	192	8	1996
1	I2138	RAMP E-N	I 15	0	505	1	335	457	8	1996
1	B636	AMARGOSA RIVER	US 95	45	605	2	305	143	8	1996
1	B1405	LAS VEGAS WASH	FAS 147	10	605	3	488	131	7	1996
1	B1805	RED ROCK WASH	FAS 159	17	605	2	305	137	7	1996
1	G2012	HIGHLAND & SPRR & INDUS.	FAU 590 DESERT INN	0	605	10	594	308	8	1996
1	H1212	US 95	VEGAS DRIVE	1	605	2	335	117	7	1994
1	H1214	US 95	SMOKE RANCH	0	605	2	335	117	7	1994
1	B I1210	US 95	FAU 595	32	605	2	351	314	7	1994
1	I1213	US 95	LAKE MEAD BLVD	0	605	2	335	354	8	1994
1	I1216	US 95	CHEYNNE AVE	0	605	2	335	296	7	1994
1	I1219	US 95 & CONCRETE CHANNEL	SAR 744	0	605	2	335	296	8	1994
1	I1221	US 95	ANNE ROAD RAMP	32	605	2	488	107	8	1997
1	I1415	US 95	ANNE ROAD	35	605	2	469	411	8	1996
1	I1456	US 95	FAU 594/RUSSELL RD	29	605	2	360	311	7	1996

Table 2.1 con't: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
1	I1900	US 95	WAGONWHEEL FLYOVER	0	605	3	518	119	8	1994
1	I1964N	PECOS ROAD	I 215	0	605	2	344	192	8	1997
1	I1964S	PECOS ROAD	I 215	0	605	2	344	192	7	1997
1	I1966N	EASTERN AVENUE	BELTWAY (I215)	0	605	2	320	192	8	1996
1	I1966S	EASTERN AVENUE	BELTWAY (I215)	0	605	2	320	192	8	1996
1	I1969	BELTWAY (I 215)	WINDMILL LANE	3	605	2	271	369	7	1996
1	I1973N	AIRPORT CONNECTOR RAMPS	I 215	0	605	1	454	239	8	1994
1	I1973R	AIRPORT CONNECTOR RAMP	I 215 RAMP	0	605	5	351	94	8	1994
1	I1973S	AIRPORT CONNECTOR RAMPS	I 215	0	605	1	454	239	8	1994
1	I1977	AIRPORT CONNECTOR	SUNSET ROAD	20	605	3	472	314	7	1994
1	I1980	I 215	FAS 604	0	605	2	442	369	7	1994
1	I1983N	I 215 RAMP	I 15	0	605	2	335	192	8	1996
1	I1983S	I 215 RAMP	I 15	0	605	2	335	192	8	1996
1	I1984N	I 215	I 15	17	605	2	482	223	8	1994
1	I1984S	I 215	I 15	17	605	2	451	223	8	1994
1	I1986	I 215	RAMP R4	99	605	2	384	146	8	1995
1	I1987	RAMP R9	RAMP R4	20	605	1	411	131	9	1994
1	I1989	I 215	INDUSTRIAL ROAD	15	605	2	427	207	8	1994
1	I1990	RAMOS R5 & R9	INDUSTRIAL ROAD	26	605	2	543	207	8	1994
1	I2006	I 15 RAMP	I 215 RAMP	0	605	3	369	131	8	1994
1	I2135	RUSSELL ROAD	PARADISE ROAD	0	605	1	591	247	8	1994
1	H1218	US 95 & CONC CHANNEL	ALEXANDER ROAD	1	605	2	335	117	8	N/A
1	H1220	US 95	LANE MOUNTAIN RD	0	605	2	335	117	8	N/A
1	H1446	FAU 589	I 515	24	605	3	378	443	7	N/A
1	H1458	US 95	HARMON AVENUE	1	605	2	341	255	7	N/A
1	H1460	GIBSON ROAD	US 95	64	605	2	564	369	7	N/A
1	H1804	US 95	STEPHANIE STREET	10	605	2	338	155	7	N/A
1	H1697N	PEBBLE ROAD	BELTWAY (I215)	37	605	2	335	192	8	N/A
1	H1697S	PEBBLE ROAD	BELTWAY (I215)	37	605	2	332	192	8	N/A
1	H1968	BELTWAY (I 215)	WIGWAM AVENUE	15	605	0	399	250	7	N/A
1	H1974	AIRPORT CONNECTOR	PILOT ROAD	10	605	3	287	189	7	N/A
1	H1976	AIRPORT CONNECTOR	GRIER DRIVE	11	605	3	323	189	7	N/A
1	H1979	I 215	GILLESPIE STREET	0	605	2	415	296	8	N/A
1	H2013	DESERT INN	LAS VEGAS BLVD	0	605	2	158	776	7	N/A
1	H2013W	DESERT INN	DAVE DRIVE	0	605	2	158	224	8	N/A
1	H2079N	SPENCER STREET	BELTWAY (I215)	35	605	2	287	192	8	N/A
1	H2079S	SPENCER STREET	BELTWAY (I215)	35	605	2	283	192	8	N/A
1	H2136N	WRIGHT BROTHERS LANE	PARADISE ROAD	99	605	4	427	119	8	N/A

Table 2.1 con't: Post-Tensioned, Box-Girder Bridges in Northern and Southern Nevada

County	Bridge Number	Feature Intersected	Facility Carried	Skew	Type (Main)	Number Spans	Length Max. (.1m)	Width O-O(.1m)	Deck Rating	Year Built
1	H2136S	WRIGHT BROTHERS LANE	PARADISE ROAD	99	605	2	457	119	8	N/A
1	H2348	DESERT INN ROAD	IN/OUT CONVENTION	0	605	2	164	243	8	N/A
1	H2349	DESERT INN ROAD	IN/OUT CONVENTION	0	605	2	160	122	8	N/A
1	H2350	DESERT INN ROAD	IN/OUT CONVENTION	0	605	2	160	122	8	N/A
1	I806N	FAU 591 SPRING MTN. ROAD	I 15	2	605	2	366	259	7	N/A
1	I806S	FAU 591 SPRING MTN. ROAD	I 15	2	605	2	366	260	7	N/A
1	I1207	US 95	VALLEY VIEW ST	6	605	2	335	247	7	N/A
1	I1208	US 95	FAU 597	0	605	2	351	399	7	N/A
1	I1209	FAU 596	US 95	0	605	3	408	367	6	N/A

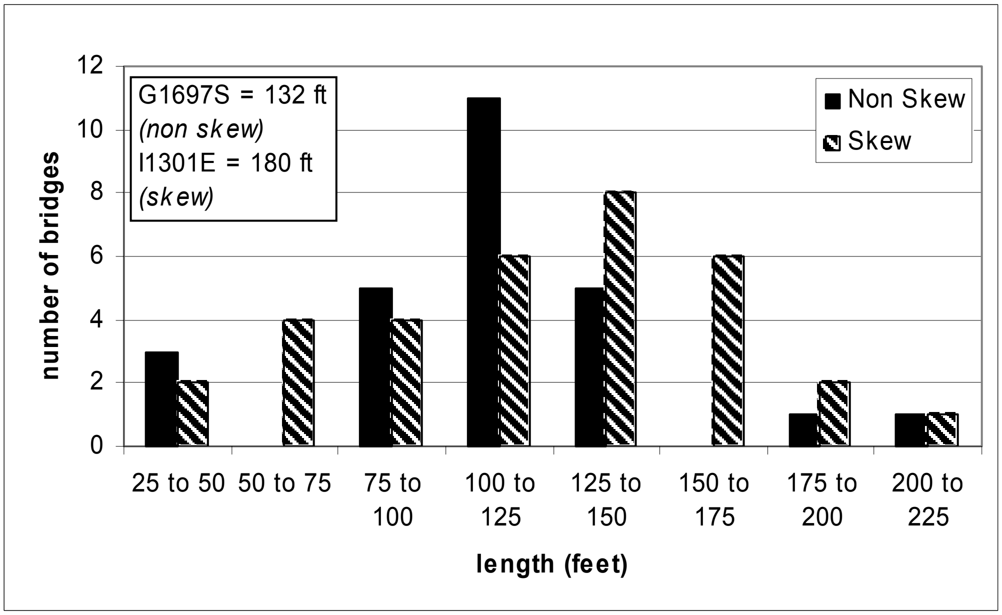


Figure 2.1: Distribution of Simple Span Bridge Lengths
County Groups 2 and 3

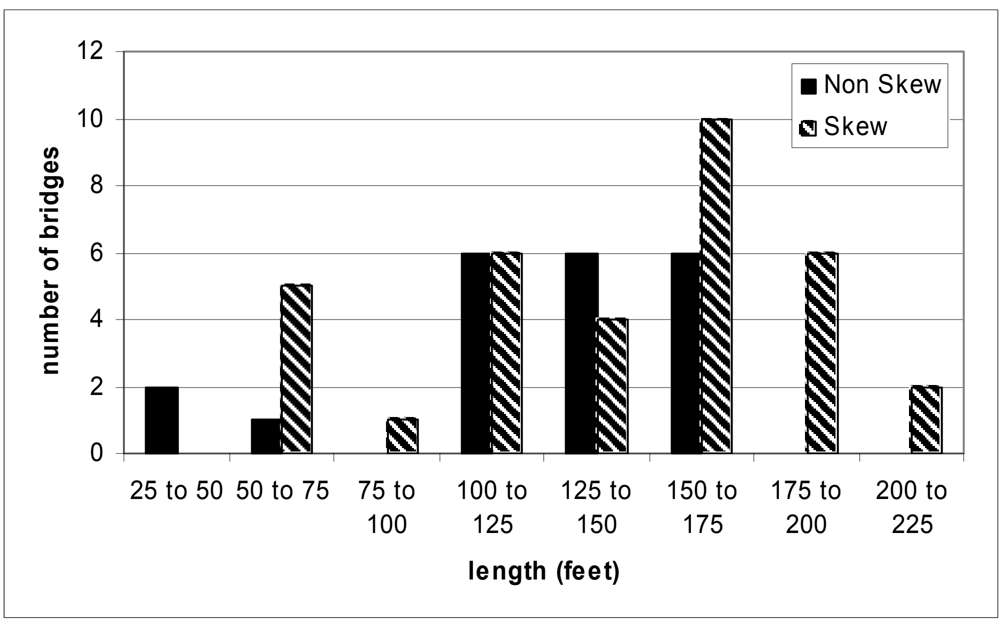


Figure 2.2: Distribution of Simple Span Bridge Lengths County Group1

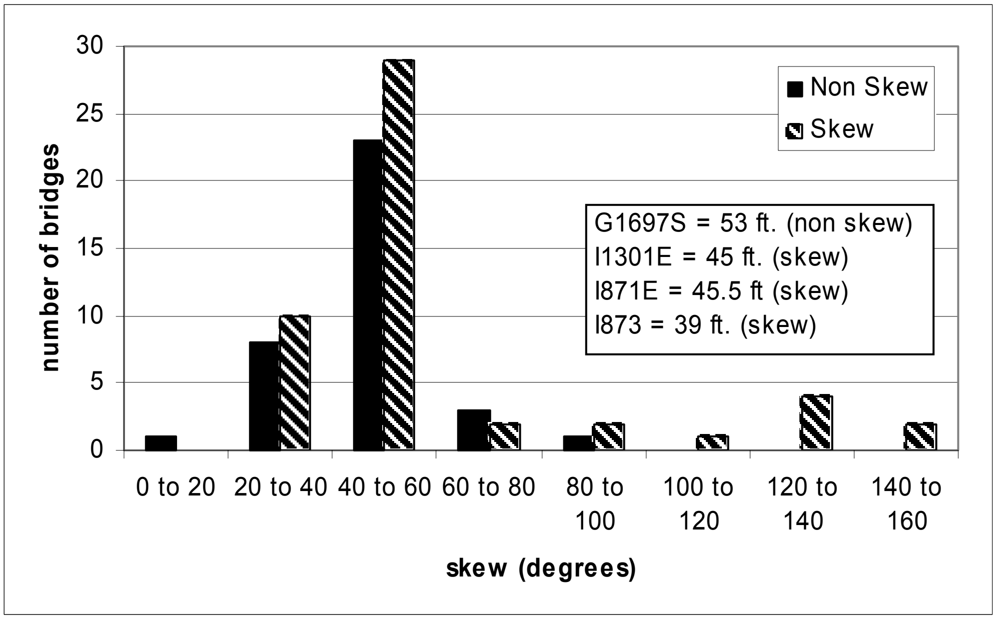


Figure 2.3: Distribution of Simple and Continuous Span Bridge Widths County Groups 2 and 3

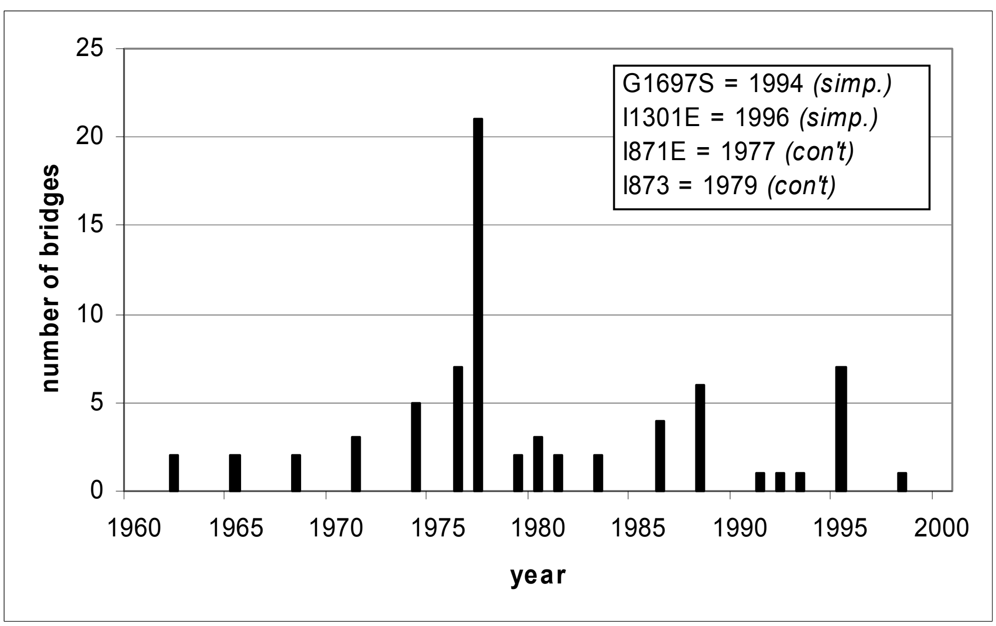


Figure 2.4: Distribution of Simple and Continuous Year of Construction County Groups 2 and 3

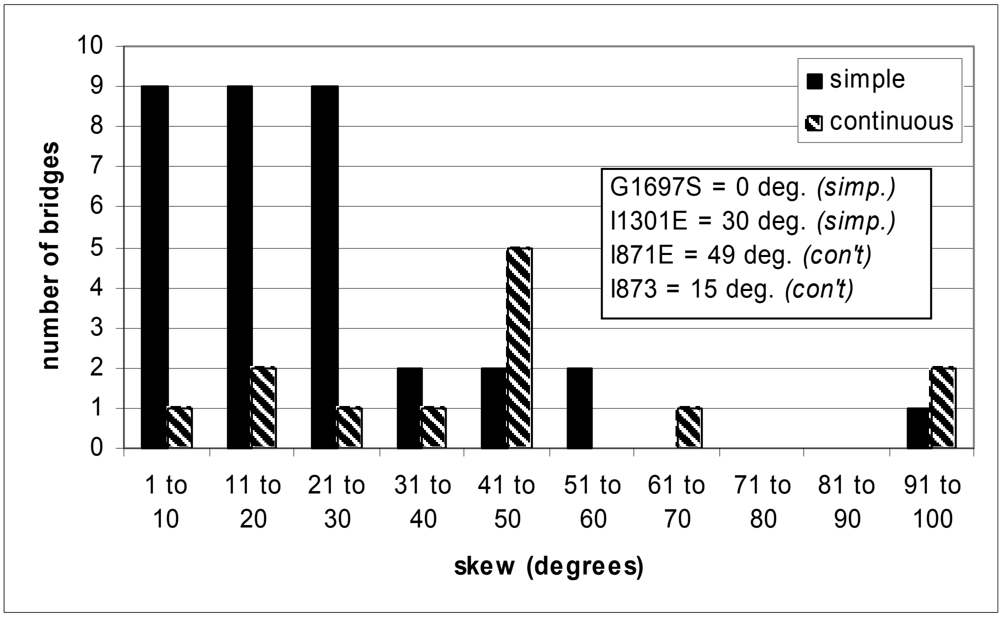


Figure 2.5: Distribution of Degree of Skew County Groups 2 and 3

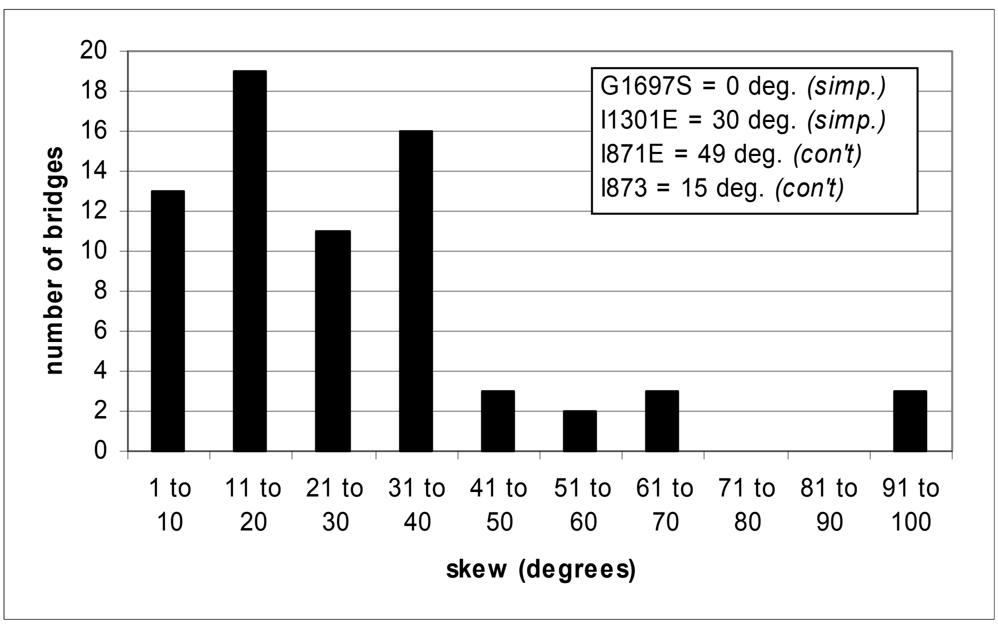


Figure 2.6: Distribution of Simple and Continuous Degree of Skew County Group 1

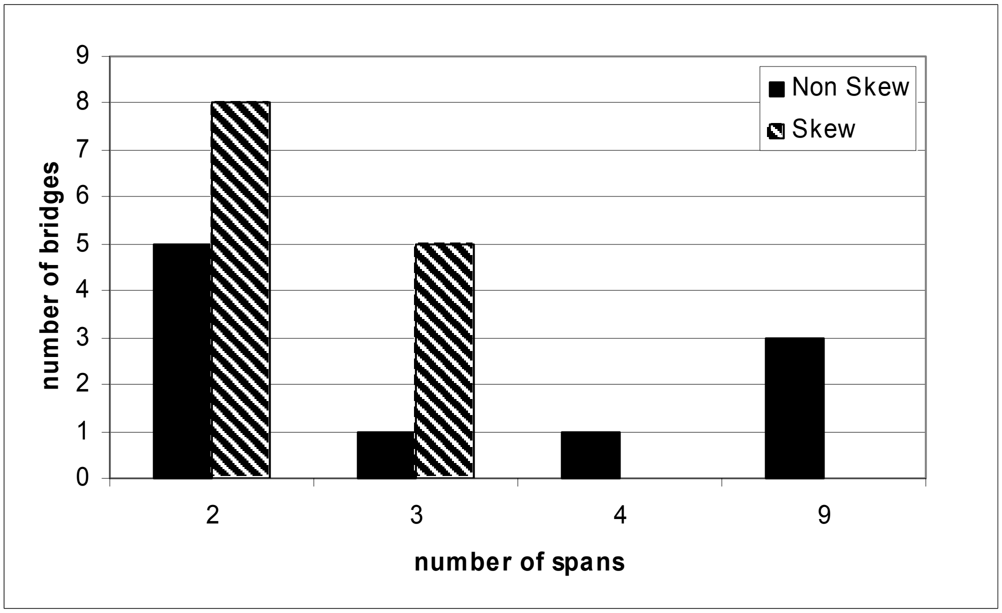


Figure 2.7: Distribution of Continuous Span Bridges County Groups 2 and 3

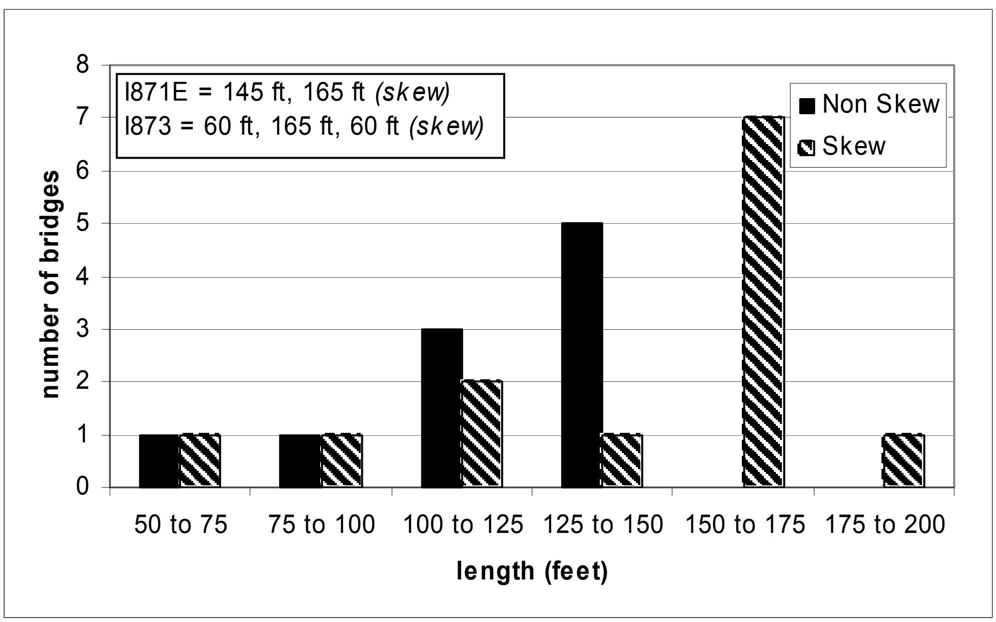


Figure 2.8: Distribution of Continuous Span Bridge Lengths County Groups 2 and 3

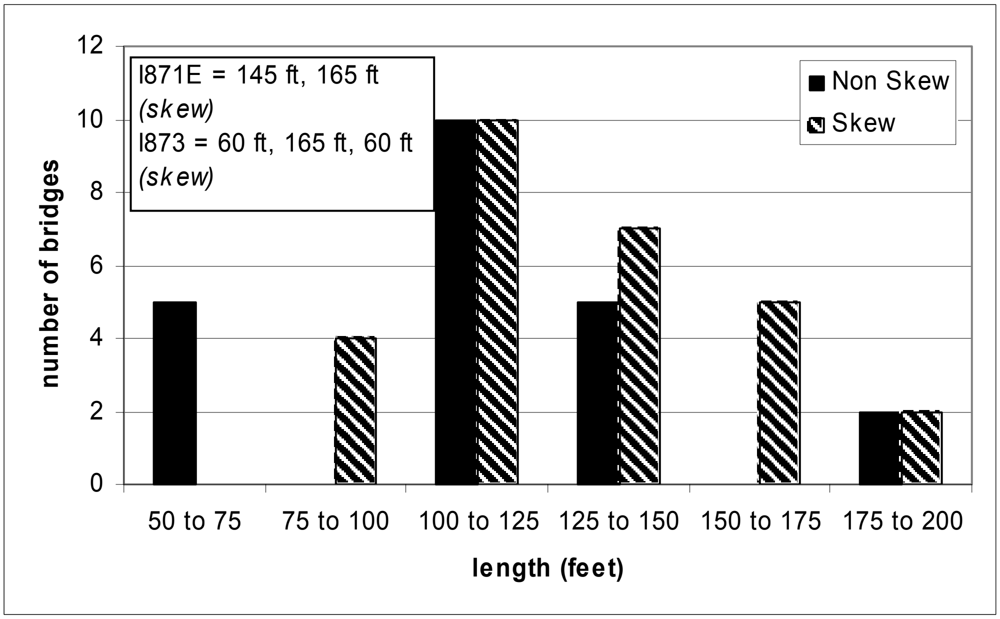


Figure 2.9: Distribution of Continuous Span Bridge Lengths
County Group 1

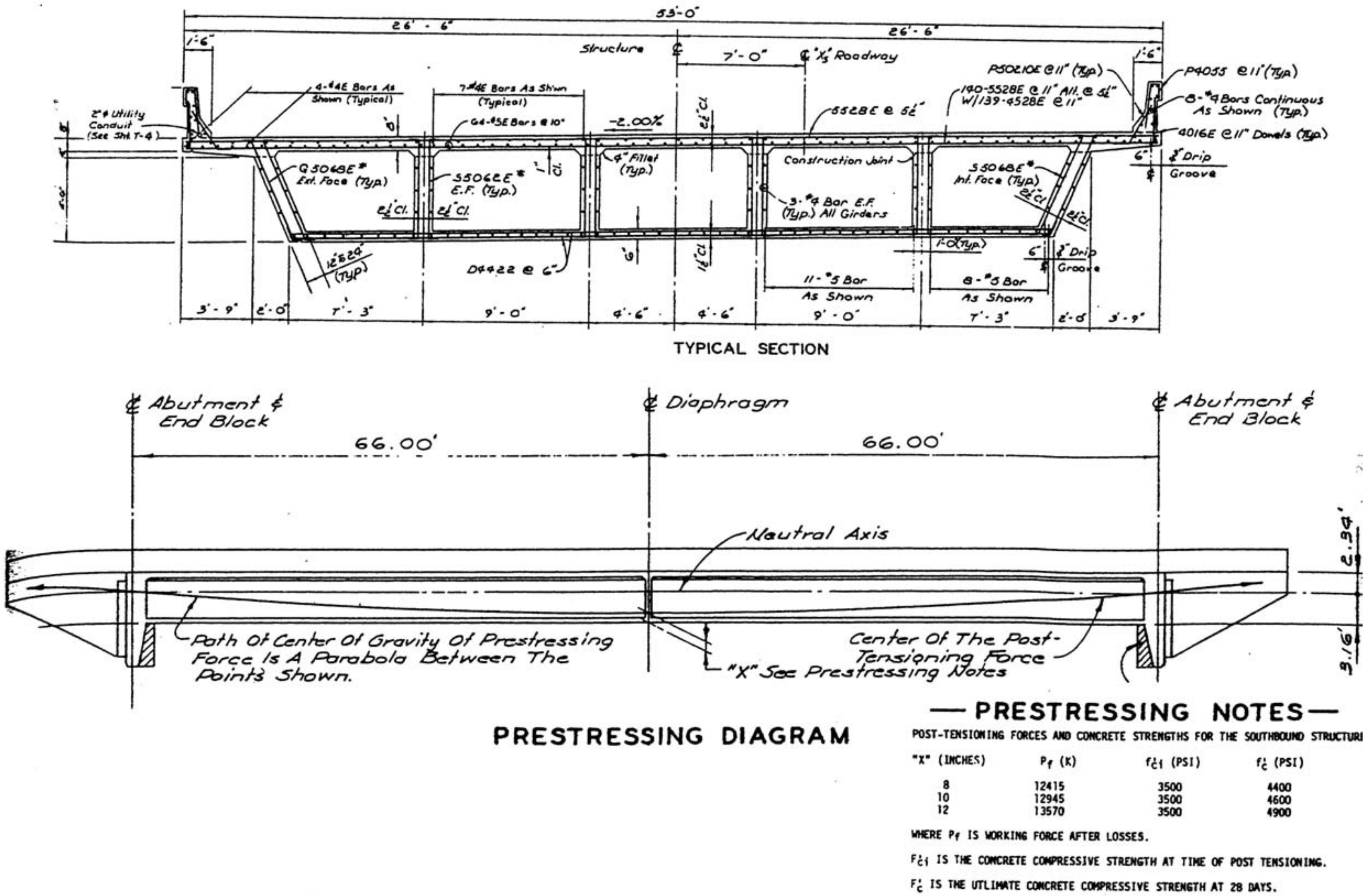


Figure 2.10 Bridge G1697S Typical Section and Prestressing Diagram

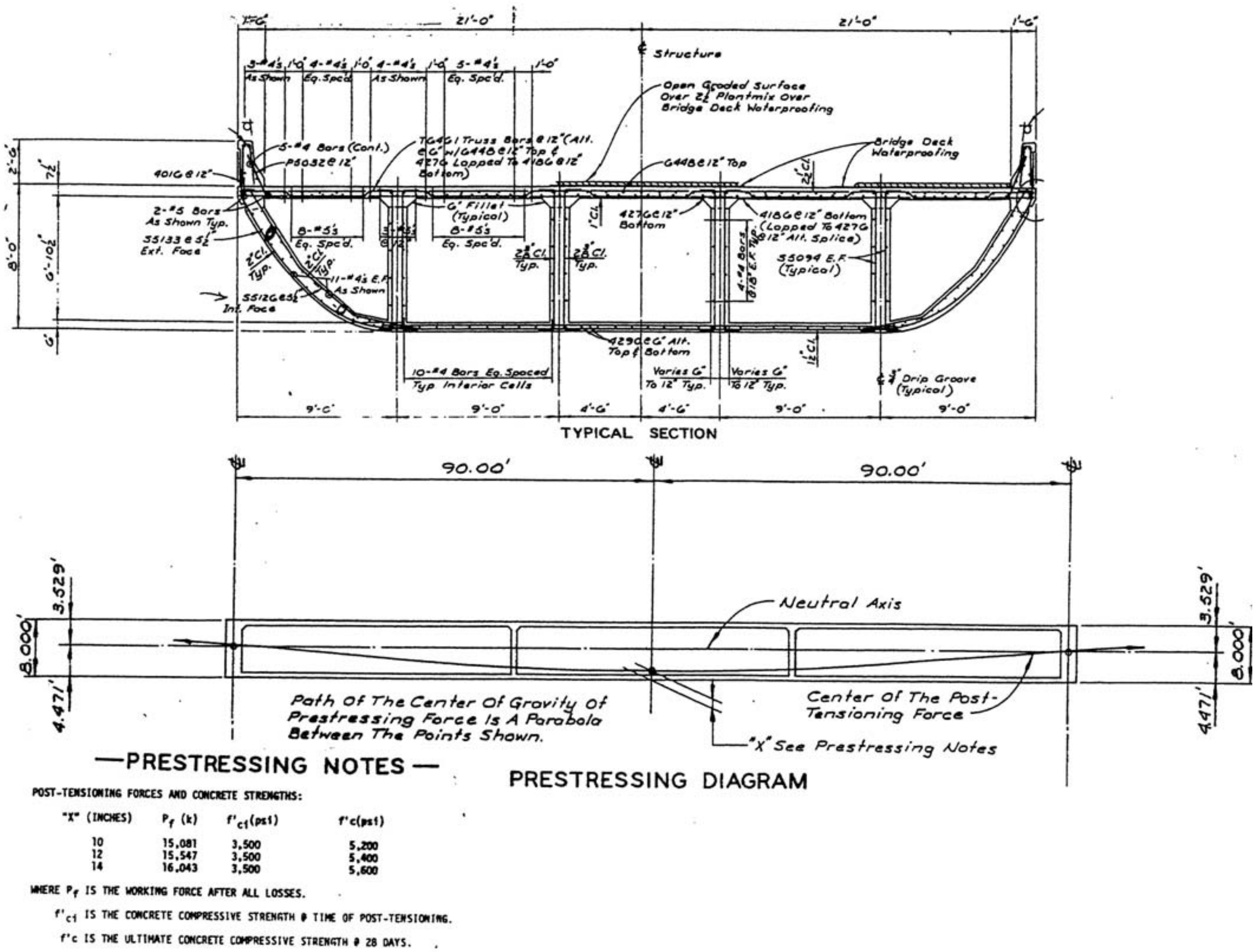
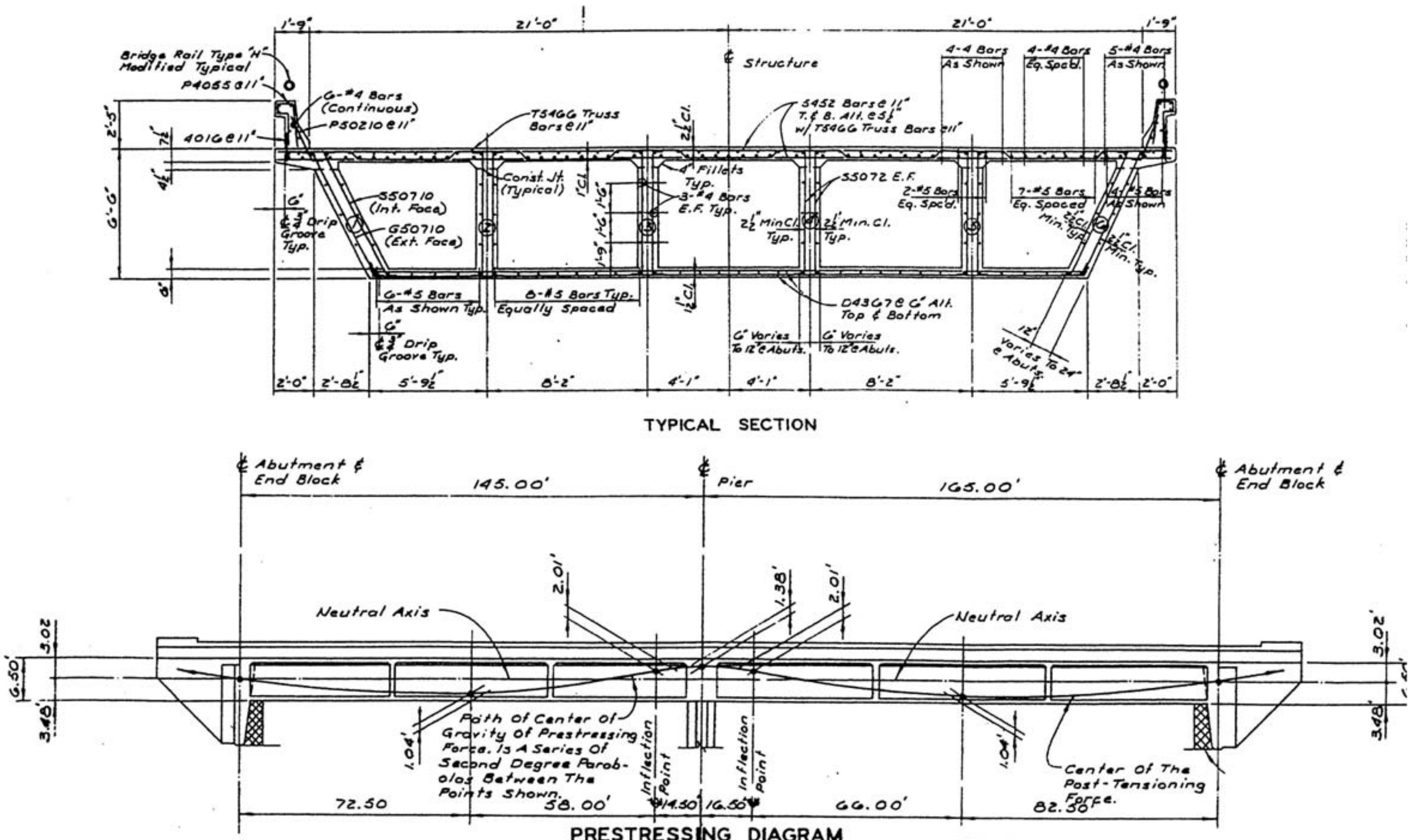


Figure 2.11 Bridge I1301E Typical Section and Prestressing Diagram



—PRESSTRESSING NOTES—

*Pjack = 15,754 KIPS TOTAL AT JACKING ENDS, $A_s = \frac{P_{jack}}{.75f'_s}$

CONCRETE f'_c = 4,400 PSI @ 28 DAYS, f'_{ci} = 3,500 PSI @ TIME OF STRESSING.

Figure 2.12 Bridge I871E Typical Section and Prestressing Diagram

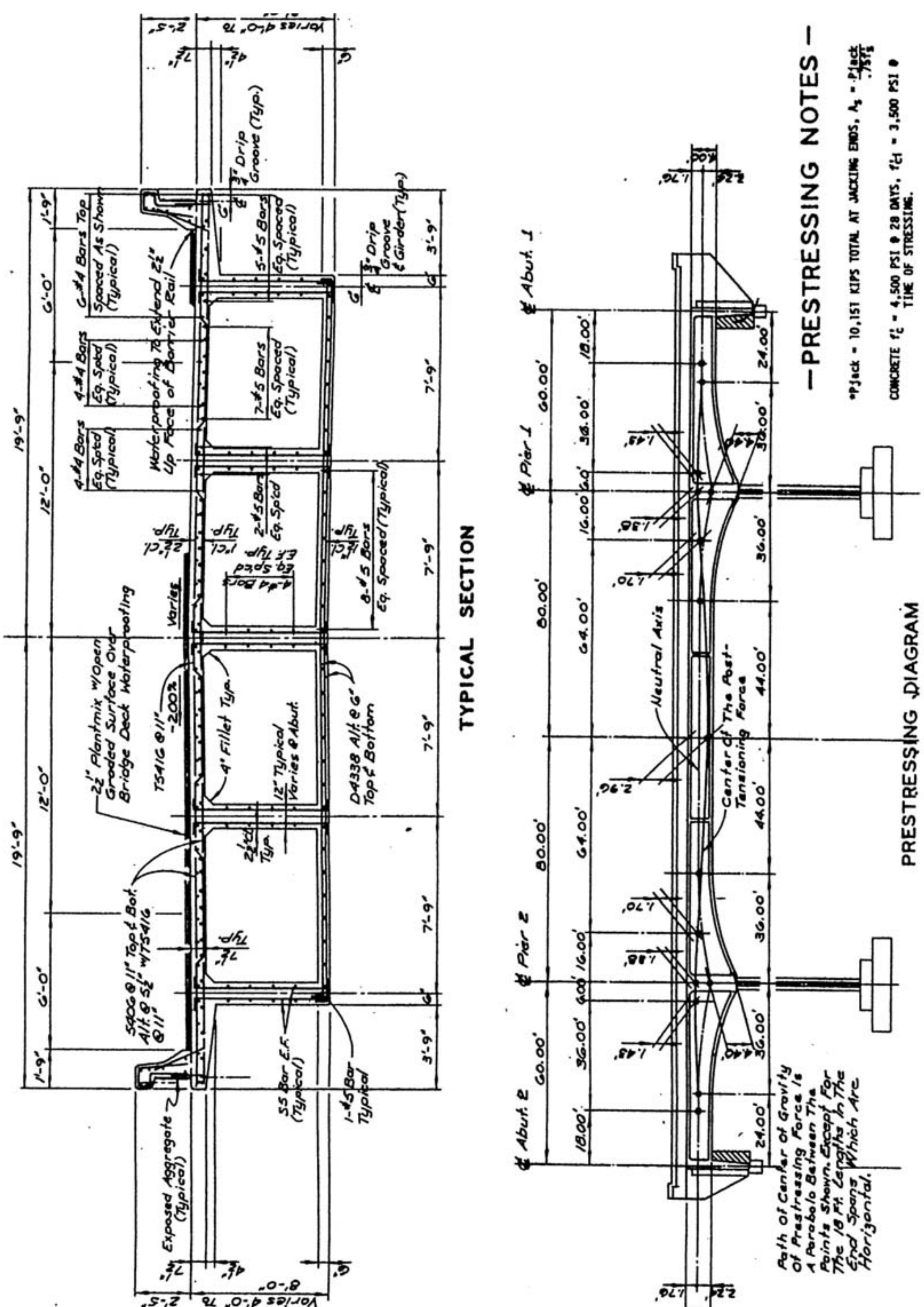


Figure 2.13 Bridge I873 Typical Section and Prestressing Diagram

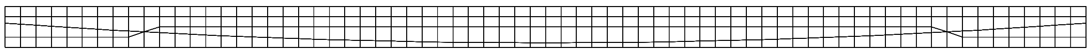


Figure 2.14: Elevation View Bridge G1697S

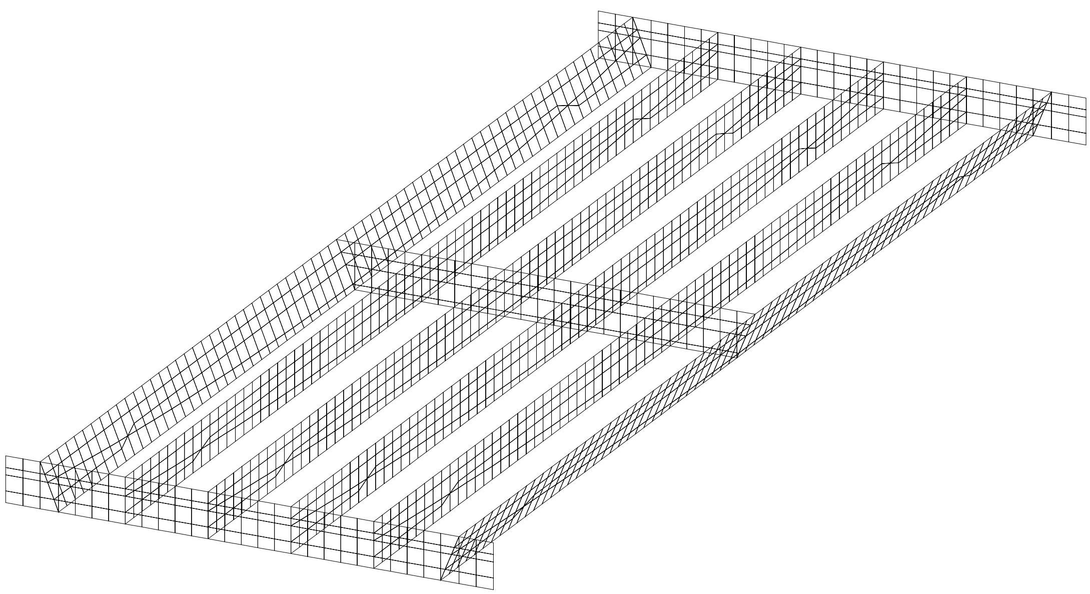


Figure 2.15: Bridge G1697S Shown Without Bottom Sofit and Top Deck

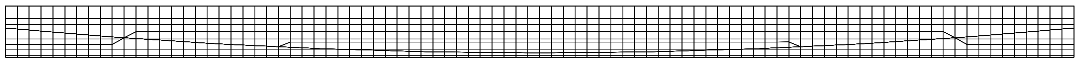


Figure 2.16: Elevation View Bridge I1301E

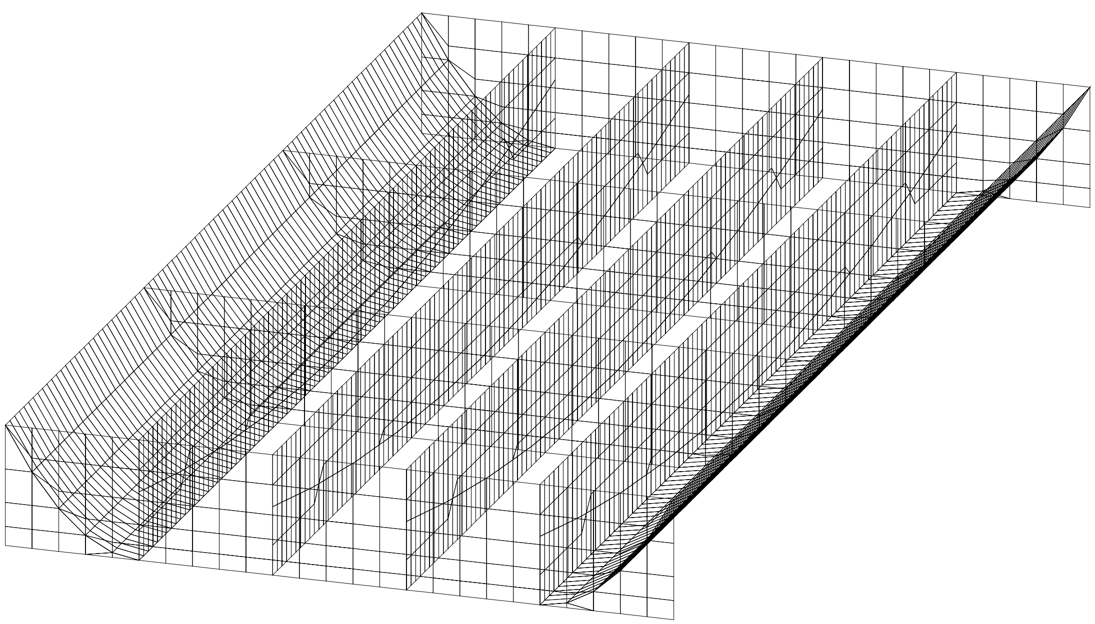


Figure 2.17: Bridge I1301E Shown Without Bottom Sofit and Top Deck

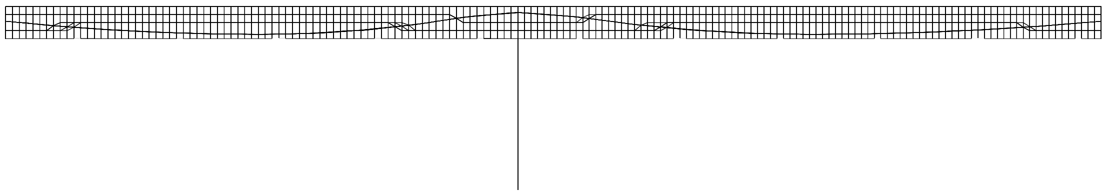


Figure 2.18: Elevation View Bridge I871E

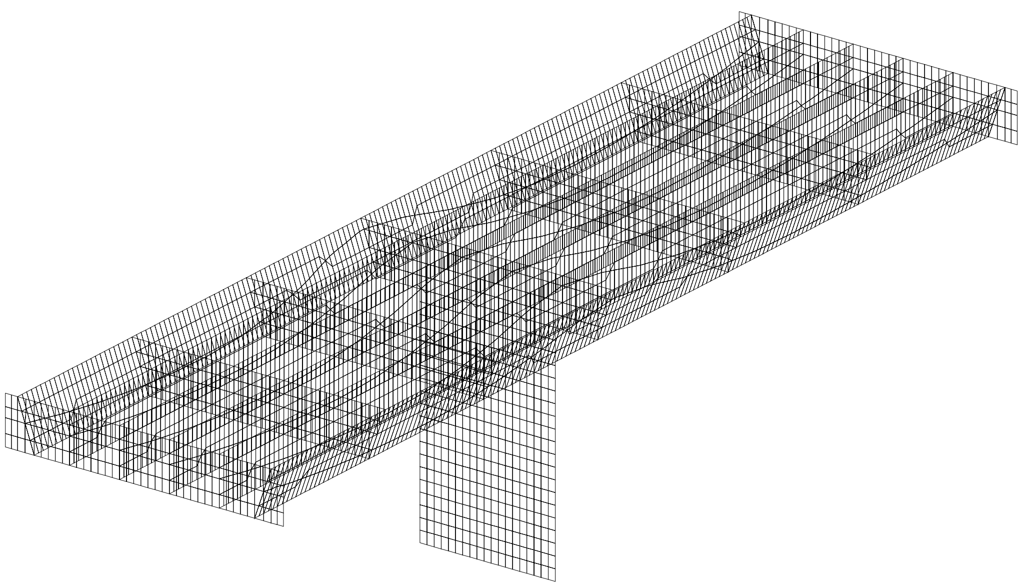


Figure 2.19: Bridge I871E Shown Without Bottom Sofit and Top Deck

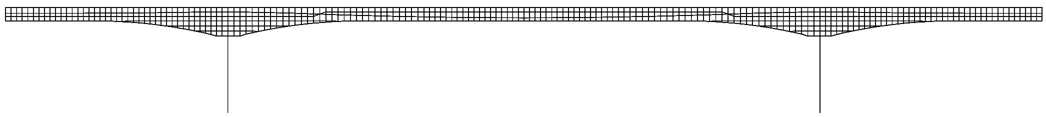


Figure 2.20: Elevation View Bridge I873

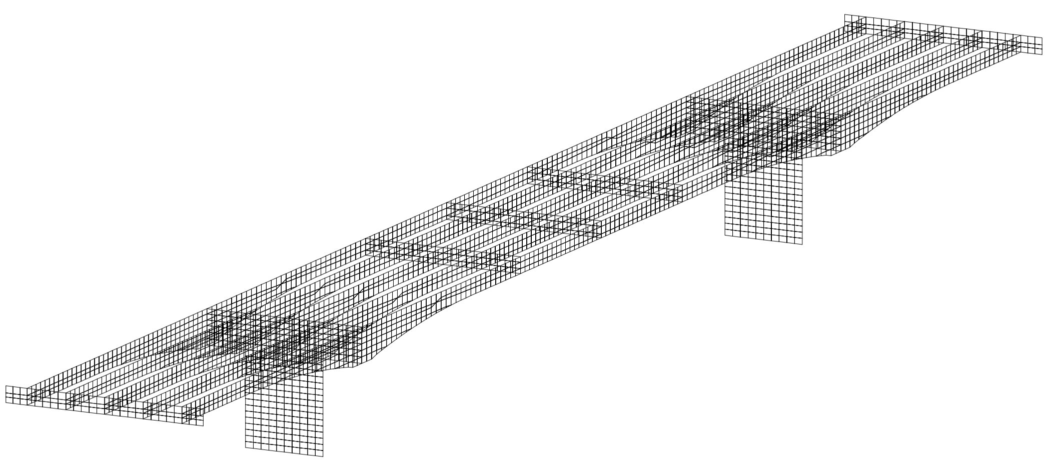


Figure 2.21: Bridge I873 Shown Without Bottom Sofit and Top Deck

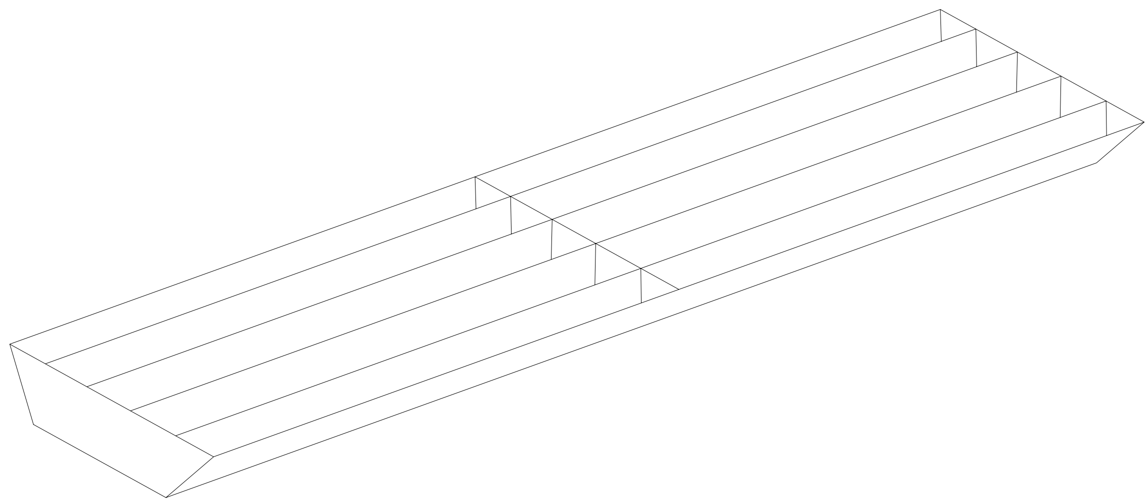


Figure 2.22: Bridge with No Deck Properties. Used for Stage 1 and Stage 2 in 3D Finite Element Analysis

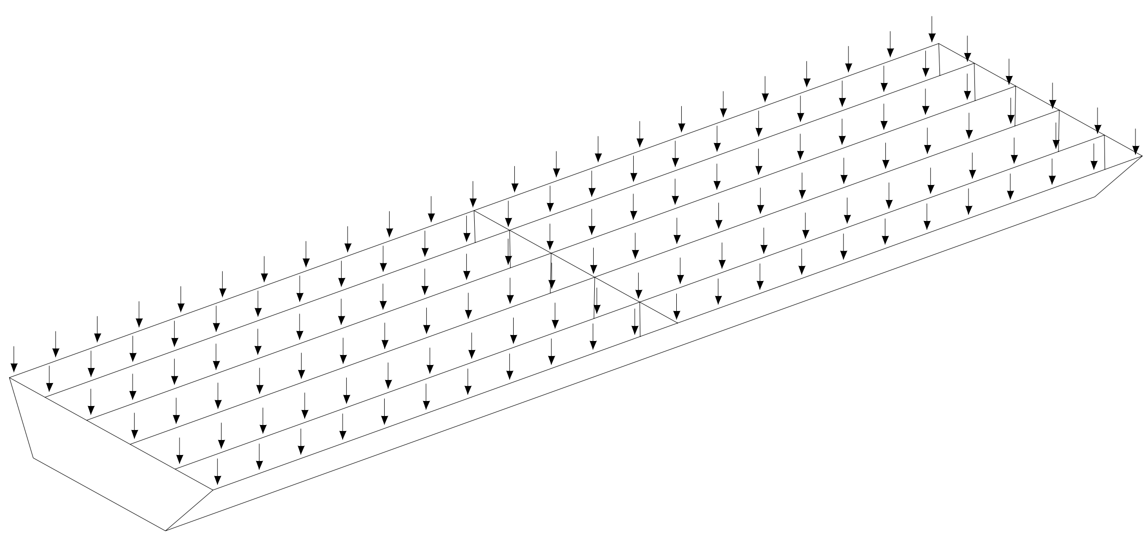


Figure 2.23: Bridge with No Deck Properties and an Additional Dead Load Applied at Each Girder. Used for Stage 3 in 3D Finite Element Analysis.

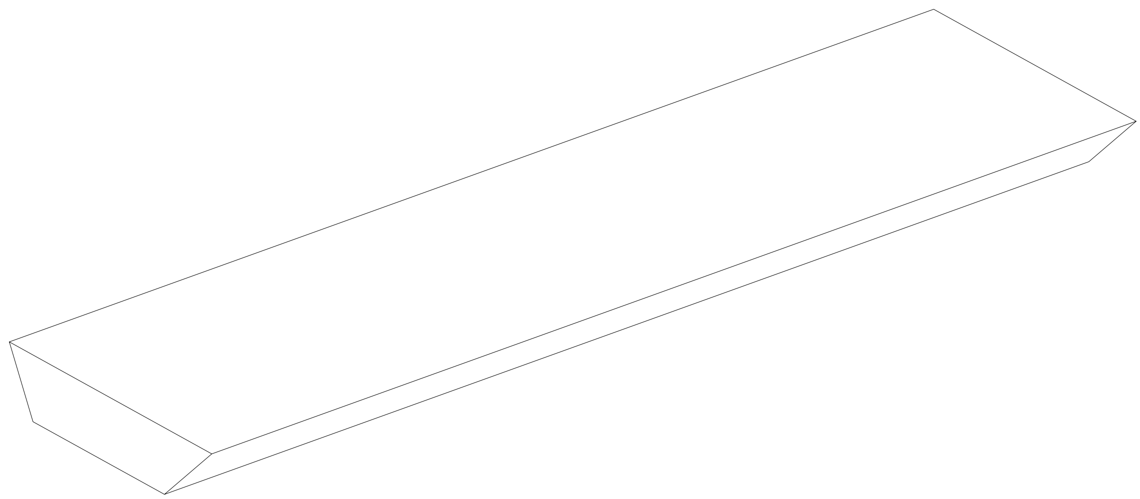


Figure 2.24: Bridge with Full Deck Properties. Superimposed with Figure 2.23 to achieve Stage 4 in 3D Finite Element Analysis.

Chapter 3

Simple Span Bridges

3.1 General Comments

Two different bridges were used to analyze deck removal for the simple span bridge decks. The first bridge (G1697S) crosses over the Union Pacific Railroad tracks on U.S. Route 395. It was built in 1981 with one single span of 132 feet in length, no skew, and has a width of 53 feet. The second bridge (I1301E) intersects the FAU 651 on Interstate 80. It was built in 1996 with one single span of 180 feet in length, 30 degrees of skew, and has a width of 50 feet. Even though both bridges were built later than the average bridge construction date of 1977, it was felt that these specific bridges represented a good proportion of bridges in the Northern Nevada region.

The solution of removal and replacement of bridges, for simple span bridges, was based on basic strength of materials principles, as in Eq 3-1.

$$f = -P/A + -Pey/I + My/I \qquad \text{(Eq 3-1)}$$

f = Stress in the critical section of the bridge.
P = Amount of prestress in the system at the critical section.
A = Cross-sectional area of concrete of the bridge at the critical section.
e = Eccentricity of the bridge tendon at the critical section.
y = Distance from the center of gravity to the extreme fiber at the critical section.
M = Dead load moment for the bridge system at the critical section.
I = Moment of Inertia of the bridge system at the critical section.

Eq 3-1 was used in developing a process to remove and replace the bridge deck. It will be shown in Chapter 3 that the solution for removal and replacement of the decks, for simple span bridges, is to attach additional prestressing tendons on the bottom sofit of the bridge to give additional support to the structure during deck replacement. An anchoring system was designed to attach the additional tendons to the interior girders of the bridge.

Anchoring to the girders was the most effective way to get maximum benefit out of the additional prestressing. This chapter will describe the analysis leading up to the decision to use post-tensioning. It will show the impact of post-tensioning as well as how to design the system.

3.2 Goals for Removing and Replacing

The main objective in the removal and replacement of cast-in-place, post-tensioned, box-girder bridge decks is to keep the economic cost of removing the deck under the economic cost of tearing down the whole bridge and erecting a full new bridge. Even though the main goal of the project is in the economic comparison, other engineering goals and objectives had to be kept in mind as well.

The first main objective was to keep the stress below assigned design values in the extreme tensile fiber and the extreme compression fiber, as the deck was removed and replaced. For the extreme compression fiber, a maximum compression stress of $0.70f'_c$ was used, an increase of about 17% from the code value of $0.60f'_c$ (Ref. AASHTO 5.9.4.2.1) for prestress plus total load. Increase in the permitted stress was done because the increase in stress would be temporary. AASHTO reduces stresses for long-term effects by 0.85. The inverse of 0.85 is 1.17. The original design f'_c was increased by 10% because the concrete in the bridge is well past its 28-day strength. For the extreme tensile fiber, a maximum stress of $6\sqrt{f'_c}$ is stated by AASHTO 5.9.4.2.2.

The next objective was to remove as much of the deck as possible. It was hoped that it would be possible to take all of the deck off at one time. It was felt that this would help construction time tremendously and reduce costs of replacing the deck.

3.3 Comparing the 2D analysis with the 3D analysis

It was decided to do several of the analyses in both 2D (BDS) and 3D (SAP-2000) to verify performance and the accuracy of both models. Table 3.1a and Table 3.1b show the comparison between the 3D analysis results with the 2D analysis results for the two simple span Bridges G1697S and I1301E. The comparison has been done for two separate cases: (1) the original full deck in place with combination of the bridge's structure weight and interior post-tensioning effective, Table 3.1a; and (2) when the deck has been completely removed, dead load includes the weight of the deck and interior post-tensioning effective, Table 3.1b. Summaries of the 3D analysis full deck case, Bridges G1697S and I1301E, are shown in Figures C.1 through C.4. The graphs in the appendix show different stress levels along the width of the bridge at tenth points along the span of the bridge. Each graph represents a stress reading at 0.10 times the span length. The bumps in the graphs along the width of the bridge represent stress readings at the girder/webs. Stresses are relatively higher at the girders than at points along the deck, due to the stiffness of the girder. The maximum values in the graphs, either tensile or compressive, are then summarized in the tables. Summaries of the 3D analysis results for the no deck case, Bridges G1697S and I1301E, are shown in Figures C.5 through C.8. To compare the 2D and 3D analyses, an average of the top and bottom node stresses was performed. Looking at Table 3.1a and Table 3.1b, it is shown that the difference between the average SAP 2000 3D and the BDS 2D results range from 0.9 to 1.10 of each other, except at the ends and middle where the diaphragm is located. At these locations, the 3D analysis picks up localized stresses not seen in the 2D analysis. The maximum SAP 2000 3D and the BDS 2D results have larger discrepancies than the average SAP 2000 3D and the BDS 2D. One discrepancy is with Bridge I1301E for the no deck property case.

Bridge I1301E, for the 3D SAP 2000, analysis has smaller tensile stress on the bottom fiber and a smaller compressive stress on the top fiber when compared to the 2D BDS analysis. This is an acceptable tolerance for error between a 2D analysis and a 3D analysis. Even though there is a slight difference in the no deck property case, the full deck property case is very close to each other, and the error tolerance for Bridge I1301E is acceptable. Analyzing the data between the 2D and 3D cases, it is shown that the bridges are acting the same when the deck is being removed. It is shown through the data that the compressive stresses at the top fiber are getting higher for both the 3D and the 2D case. Therefore, a level of confidence is developed that the future analysis of the 3D model with additional prestressing will be accurate, and that the results will be within tolerance. It was felt that the 3D analysis was necessary in order to determine the impact of skew.

3.4 Problem With Full Replacement of Deck

Taking off and fully replacing the deck of simple span bridges results in stresses that exceed the assigned limit values. Table 3.2 shows the stress levels when the bridges has had the deck removed and the "wet soggy" deck is placed on the bridge for Bridge G1697S and I1301E. Table 3.2 summarizes the 3D analysis results in Figures C.9 through C.12. Table 3.2, shows that the compressive stresses at the top fiber for both bridges are well over $0.7f'_c$ (3504 psi for Bridge G1697S, 4062 psi for Bridge I1301e) and the tensile stresses on the bottom fiber are close and sometimes exceed the code value of $6\sqrt{f'_c}$ (849 psi for Bridge G1697S, 914 psi for Bridge I1301E). In remaining tables where stresses are shown, the compression stress ratios shown are f_c/f'_c, and the tensile stress ratios shown are $f_c/\sqrt{f'_c}$. The stress in the bridge is "fc" and "f'c" is 1.10

multiplied by f'c at 28 days. Compression stress ratios are distinguished with a 'c' and tensile stress ratios are distinguished with a 't.' The stress levels determined for the simple-span bridge are not acceptable. Either shoring or additional prestressing will be required during construction to keep the stress levels below the code limit values. The simple span bridges were also analyzed taking the deck off in stages. After adding all the stresses together, a result was obtained that is similar when removing and replacing the deck without any additional prestressing or shoring.

3.5 Finding the Amount of Deck Removal and Additional Prestressing

As stated in Section 3.2, the first objective was to keep the critical stresses below the limit values, while trying to remove as much deck as possible during the deck rehabilitation. Section 3.4 shows that additional prestressing or shoring is needed to keep the stress levels below the limit values. Next, the amount of deck that can be removed while additional prestressing is present needs to be evaluated. Figure 3.1 shows the concept of deck removal. Table 3.3 shows the stress values of different levels of deck removal when the additional prestress is added to the bottom sofit. A constant additional prestressing force was used and is described later in Section 3.5. All trials were done on the non-skewed bridge (G1697s) and then applied, with the same theory and procedure described in Chapter 2, to the skewed bridge (I1301E). The trial values for variable amounts of deck removal after the additional prestress has already been added can be seen in Table 3.3. The 3D finite element results summarized in Table 3.3 can be found in Figures C.13 through C.24. Figures C.13 through C.24 show the stress levels, either tensile or compressive, at each tenth point along the length of the bridge. The critical stresses in the system are the compression stresses at the bottom sofit of the bridge. The additional prestressing tendon path can be seen in Figure 3.2, using l_{an} as 9 feet and D_{bl} as 2 feet. This type of additional presstrssing tendon path was used to create more uplift in the bridge. Both of these values will be described later in Chapter 3.

Figure 3.3 shows the pattern of deck removal to stress ratios shown in Table 3.3. Even at 100% of deck removal, the maximum compression stress is approximately $0.45f'_c$, which is less than the allowable value of $0.70f'_c$. As more deck is removed (going from 50% deck removal to 100% deck removal) the bottom fiber becomes more compressive as the top fiber becomes more tensile. The analysis, summarized in Table 3.3, was conducted with a constant 900 kips per girder, because it was assumed that additional prestress values needed would never exceed 900 kips per girder. It was felt that if the top fiber was kept under the tensile limit values for 900 kips per girder, any additional prestress less than 900 kips per girder would be adequate in construction and stresses would be safe. The maximum value of 900 kips per girder was assumed based on several finite element analyses, and also using engineering judgment. Looking at Table 3.3, it is shown for 100% deck removal, at 900 kips per girder, stress values are not close to reaching their maximum values. Therefore, 100% of the full deck can be removed safely without ever reaching critical stresses.

After determining the amount of deck that can be removed at one time with prestress, the minimum amount of additional prestress was determined that is needed to prevent the stresses from going beyond the critical set values range. In the analysis that produced Table 3.3, a maximum possible amount of additional prestress was assumed and placed on the sofit of the bridge. This was done to reassure that the top fiber of the bridge did not go into high tensile stresses during construction. Now it is possible to determine the minimum amount of prestress needed during construction so that the top fiber would not reach critical compressive stresses. To determine the amount of additional prestress, different values of additional prestress were applied to the bridge while removing and replacing all of the deck at once. The additional prestressing tendons were set at 2 feet below the bottom sofit of the deck. This was set based on possible clearance situations. The eccentricity of the additional prestressing tendons may be changed, but the eccentricity value (e_{add}) in equation 3.2 must also change. This can be useful when used in overpasses and can also be useful in limiting additional prestressing values. Critical stresses for variable amounts of additional prestress for full deck removal and replacement can be referenced in Tables 3.4a and 3.4b. In Tables 3.4a and 3.4b 'DL' represents dead load, 'PS' represents prestressing force in the bridge, 'ADL' represents additional dead load due to a "wet and soggy" deck, and 'APS' represents the additional prestressing force added to the bottom sofit. The 3D finite element results are given in Figures C.25 through C.40. The analysis to find the minimum amount of prestress was done for the final stage in construction (Stage 4), because the critical compressive stresses in the top fiber are reached when the additional prestress is cut from the system. After the additional prestress is released from the system, the bridge will be under its own weight, is when the final stresses will be locked into the system and need to be under limit values. Therefore, the final stage in construction is found to be the most critical for compressive stresses. By looking at the final stage in construction in Tables 3.4a and 3.4b, the minimum amount of prestress can be determined while keeping the maximum compressive stress below $0.70f'_c$. Figure 3.4 shows the pattern of additional prestress values to stress ratio that are shown in Tables 3.4a and 3.4b. This shows that the minimum prestress value is 750 kips. The critical tensile stress of $6\sqrt{f'_c}$ was not a factor during construction. During the removal and replacement of simple span bridge decks, the system went into tension at the end abutments, which are due to different stress values along the abutment. 2D analysis does not take into account the stiff end abutments, which is why there are the end differences between the two. Since the end diaphragm abutments are fully supported, there is no need to do a 3D analysis to determine the stress in them as the difference in the end abutment values are of no concern. By referencing the figures in Appendix A, and looking at the stresses at the abutment sections, the different stress values along the end abutment can be seen. The analysis shows that the deck will be in compression under DL+PS. This is very good for durability issues and is the same as the original design.

3.6 Predicting the Amount of Additional Prestress Needed

Now that an additional prestressing force has been estimated by trial values, a simpler method needs to be developed. This will be done by formulating an equation that calculates the amount of additional prestressing force.

The first step in finding an equation that will measure the amount of prestress needed is to find the section properties at midspan for a full deck system and for a no deck system (A_c, I_{xx}, Y_{top}, Y_{bot}, and e). The next step is to write out the basic method equation including the additional prestress added to the system for the case when the deck is completely removed with the additional dead load of a wet deck. This equation is based on Equation 3-1. The third step is subtracting the additional prestress on the full composite system. This will model the final stage in construction when the deck has been completely removed, replaced, and the additional prestressing tendons have been released. Equation 3-2 is the expanded version of Equation 3-1 to model the final stage in construction.

$$f = [-P_{eff}/A_c + -P_{eff}e_{br}Y_{top}/I_{xx} + M_{full}Y_{top}/I_{xx} + -P_{add}/A_c + -P_{add}e_{add}Y_{top}/I_{xx}]_{no\ deck} - [-P_{add}/A_c + -P_{add}e_{add}Y_{top}/I_{xx}]_{full\ deck} \quad \text{(Eq 3-2)}$$

P_{eff} = Total effective prestress currently in the bridge system.
P_{add} = Total effective additional prestress added to the system.
A_c = Area of concrete of the bridge.
I_{xx} = Moment of inertia in the direction of bending.
Y_{top} = Center of gravity to the top fiber of the bridge.
e_{br} = Eccentricity to the prestressing tendons currently in the bridge system.
e_{add} = Eccentricity to the additional prestressing tendons.
M_{full} = Moment that the dead load of the full deck will generate.
$_{no\ deck}$ = Cross sectional properties at midspan with the deck fully removed.
$_{full\ deck}$ = Cross sectional properties at midspan using the full deck effective.
f = The critical compressive stress in the system. Determined to be $0.70f'_c$

The critical stress (f) is set as $0.7\ f'_c$ and ($Y_{bot} + D_{bl}$) is used for the e_{add}, where D_{bl} denotes the depth of the exterior bearing anchor for the additonal prestressing tendons, reference Figure 3.2. Since the design value of f'_c will exceed its 28-day setting strength, increasing the 28-day design value by 10% for the critical stress in the system is possible. Different section properties are used for certain times during the construction process. Where the subscript *full* is specified, all full deck section properties are to be used, and where the subscript *no* is specified, all no deck section properties are to be used. After all values are entered, P_{add} can be solved which is the additional prestress to be added in the system.

The additional prestressing value calculated is a very good estimate on what final value is to be added to the system, but there are certain losses that need to be taken into account. Unlike normal post-tensioned concrete design, long-term losses in the system do not need to be accounted for, but short-term losses are going to play a factor in the design. The only short-term losses needed to be taken into account in the design are anchorage set and elastic shortening, which is estimated to be about 5%. Elastic shortening can be accounted for approximately 3% - 4%, while anchorage setting will be limited due to the size of the anchor.

The last step is to multiply the final jacking force by an alpha (α) factor for localized stresses in the system. This was analyzed by using a constant prestressing force and moving the anchorage of the additional prestressing force to different locations along the beam. Figure 3.5 shows the pattern of the maximum stress ratios to the distance the anchorage is from the given support in Table 3.5. The values in Table 3.5 and Figure 3.5 are the maximum stress values measured along the span length. As the anchor gets farther from the abutment, the maximum compression stresses on the top fiber at midspan increases, but this is not he controlling stresses. The 3D finite element analysis results for Table 3.5 can be referenced in Figures C.41 through C.52. The 3D finite element analysis was run with only dead load of the structure and the additional prestressing anchorage on the bottom sofit. It was done this way to more accurately measure the amount of loss due to additional anchorage distance from the abutment.

$$\alpha = 2 \times l_{an}/l_{span} \qquad \text{(Eq 3-3)}$$

α: Percentage of loss due to anchorage distance from the abutment.
l_{an}: Length of the anchorage to the end abutment shown in Figure 3.4.
l_{span}: Span length.

There is a large increase in the maximum stresses at the top fiber as the anchorage is placed farther from the abutment face. While the concrete stresses were only monitored at limited locations, there are significant increases in the maximum stresses after the anchorage moves past the 10% point. Therefore, it is suggested that if the anchorage is placed within 10% of the span length from the abutment face, the localized stress factor (α) can be neglected. This can be shown in Figure 3.5 when the anchorage distance is about 17 feet from the abutment. Even though the localized stress factor can be neglected, it is shown in Table 3.6 and 3.7 that the localized stress factor results in a better correlation between the calculations and the 3D finite element analysis.

After the final additional prestressing value has been multiplied by all losses, the additional prestressing that shall be distributed between girders in the system is achieved.

3.7 Summary for Bridge G1697S

For Bridge G1697S, an additional jacking prestress force of 585 kips per girder is needed to keep the bridge under critical stresses during construction. This will be shown in the calculations for Bridge G1697S in Appendix B. Table 3.6 shows the critical stresses across the deck of the bridge at different stages in construction using an additional prestressing force of 585 kips. The 3D finite element analysis results are shown in Figures C.53 through C.60.

Stage 1 (Dead Load + Prestress) is when the deck has been fully removed from the bridge, and no additional prestressing force is acting on the system. The only force in the system is the prestressing force that is currently in the bridge. The critical stresses are at approximately midspan when the top fiber is in compression, approximately $0.65f'_c$.

Stage 2 (Dead Load + Prestress + Additional Prestress) is when the additional jacking force of 585 kips has been placed on the system. By inspection of the stresses, the bridge cambers up, making the top fiber compression stresses reduce to about $0.17f'_c$.

Stage 3 (Dead Load + Prestress + Additional Prestress + Additional Dead Load) is when the additional prestressing force on the system has taken into account short-term losses and other various losses covered in Section 3.6. Also, at this point in time, the deck has been fully placed. During this time, the deck carries no stiffness, acts as an additional load on the bridge, and is just a “soft concrete deck.”

The next column, in Table 3.6, shows the stresses caused by the additional effective prestressing force on the system, with no other type of loading. Stage 4 (Dead Load + Prestress + Additional Dead Load) is when the deck has hardened and the additional prestressing force has been released from the bridge. At this point in time, the critical stresses are at the top fiber, and are just under $0.70f'_c$, which was the target stress that was designed for in Equation 3-2.

3.8 Summary for Bridge I1301E

Table 3.7 shows the summary of results from the 3D finite element analysis of different stages of construction during the removal of the bridge deck. The actual analysis results can be referenced in Figures C.61 through C.68. The calculations are shown in Appendix B. A final additional prestressing value of 348 kips per girder was calculated.

The 30-degree skew of Bridge I1301E made little impact on the design of the bridge. Referencing Table 3.7 and comparing it to Table 3.6, the stresses do not change much from the impact of the skewed or non-skewed bridges. Table 3.8 shows the actual percent difference between the final stress values at the critical final stage in construction.

At Stage 1 of the skewed bridge, the critical stresses are at about $0.51f'_c$ and stay at about the same level as the non-skewed bridge. The end result, based on the 3D finite element analysis, of Stage 4 is about $0.68f'_c$, which is also just under the predicted value ($0.70f'_c$) using Equation 3.2. This reinforces the limited impact of skew since Equation 3.2 does not include skew.

In conclusion, the impact of skew on bridge decks is not seen in the removal and replacement of decks in simple-span post tensioned box girder bridge decks. Looking at the analysis results, the critical variables of the problem are length of the bridge, section properties, and amount of prestress already in the system. From the analysis results, equation 3-2 was developed in determining the amount of additional prestress needed in the system to account for the “wet” concrete decking during the pouring of the deck. Using Equation 3-2, and using basic design principles, the decks in simple span bridges can safely be removed and replaced during construction while keeping the stresses under specified critical range. Based on the analysis and data provided, the simple analysis can be done instead of conducting a 2D or 3D analysis when removing and replacing decks in simple span bridges. Simple calculations can be performed as provided in Appendix B.

Table 3.1a: Comparison of 3D and 2D Analysis of Bridge G1697S and I1301E

Full Section										
Bridge G1697S							Max. SAP 2000 / BDS		Avg. SAP 2000 / BDS	
Length (ft)	Max. SAP 2000 (psi)		Avg. SAP 2000 (psi)		BDS (psi)					
	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber
0	-373	-223	-258	-151	-647	-541	0.577	0.412	0.398	0.278
13.2	-894	-608	-864	-577	-854	-650	1.047	0.935	1.012	0.888
26.4	-1026	-581	-995	-571	-936	-621	1.096	0.936	1.063	0.920
39.6	-1077	-533	-1054	-523	-975	-584	1.104	0.913	1.081	0.895
52.8	-1101	-508	-1086	-497	-996	-570	1.105	0.891	1.090	0.873
66	-1162	-347	-781	-306	-1002	-578	1.160	0.600	0.780	0.530
79.2	-1100	-507	-1086	-498	-996	-570	1.104	0.889	1.090	0.873
92.4	-1072	-532	-1054	-523	-975	-584	1.099	0.911	1.081	0.895
105.6	-1017	-598	-996	-571	-936	-621	1.087	0.963	1.064	0.919
118.8	-887	-660	-863	-575	-854	-650	1.039	1.015	1.010	0.884
132	-369	-220	-218	-120	-647	-541	0.570	0.407	0.337	0.222
Bridge I1301E										
0	-432	-526	-254	-170	-683	-558	0.632	0.943	0.371	0.305
18	-1090	-630	-938	-562	-1113	-534	0.979	1.180	0.843	1.053
36	-1256	-404	-1167	-367	-1330	-393	0.945	1.029	0.877	0.933
54	-1389	-285	-1316	-256	-1481	-301	0.938	0.947	0.889	0.851
72	-1457	-239	-1394	-215	-1568	-255	0.929	0.937	0.889	0.842
90	-1448	-220	-1419	-203	-1594	-254	0.908	0.865	0.890	0.801
108	-1459	-240	-1394	-215	-1568	-255	0.931	0.941	0.889	0.842
126	-1394	-283	-1319	-254	-1481	-301	0.941	0.941	0.890	0.845
144	-1260	-391	-1169	-361	-1330	-393	0.947	0.994	0.879	0.919
162	-1063	-639	-932	-535	-1113	-534	0.955	1.196	0.838	1.001
180	-384	-590	-149	-150	-683	-558	0.563	1.057	0.218	0.269

Table 3.1b Comparison of 3D and 2D Analysis of Bridge G1697S and I1301E

No Deck Section Without Deck Weight										
Bridge G1697S							Max. SAP 2000 / BDS		Avg. SAP 2000 / BDS	
Length	Max. SAP 2000 (psi)		Avg. SAP 2000 (psi)		BDS (psi)					
(ft)	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber
0	252	-117	-39	-56	-2382	-26	-0.106	4.492	0.017	2.154
13.2	-2804	-435	-2765	-265	-3750	-209	0.748	2.084	0.737	1.268
26.4	-3372	-560	-3316	-442	-3664	-426	0.920	1.316	0.905	1.038
39.6	-3264	-643	-3217	-620	-3335	-585	0.979	1.099	0.965	1.060
52.8	-3210	-694	-3134	-673	-3129	-690	1.026	1.006	1.002	0.975
66	-2117	-445	-583	-379	-3055	-738	0.693	0.602	0.191	0.513
79.2	-3212	-694	-3134	-672	-3129	-690	1.026	1.006	1.002	0.975
92.4	-3268	-642	-3217	-625	-3335	-585	0.980	1.098	0.965	1.068
105.6	-3368	-559	-3315	-483	-3664	-426	0.919	1.313	0.905	1.134
118.8	-2806	-432	-2763	-251	-3750	-209	0.748	2.068	0.737	1.201
132	235	-118	-39	-29	-2382	-26	-0.099	4.538	0.016	1.127
Bridge I1301E										
0	257	314	-96	-93	-1572	-142	-0.164	-2.214	0.061	0.653
18	-3204	326	-2554	218	-2627	315	1.219	1.034	0.972	0.692
36	-3272	361	-2871	275	-2835	280	1.154	1.289	1.013	0.982
54	-3071	227	-2995	218	-2971	245	1.034	0.927	1.008	0.890
72	-3267	215	-3066	208	-3043	232	1.074	0.927	1.008	0.897
90	-3382	181	-3085	193	-3059	227	1.106	0.797	1.008	0.850
108	-3282	220	-3063	210	-3043	232	1.078	0.948	1.007	0.905
126	-3020	226	-2988	216	-2971	245	1.016	0.924	1.006	0.882
144	-3154	293	-2854	263	-2835	280	1.112	1.045	1.007	0.939
162	-3111	252	-2486	223	-2627	315	1.184	0.800	0.946	0.708
180	323	673	80	206	-1572	-142	-0.206	-4.742	-0.051	-1.449

Table 3.2: Bridges G1697S and I1301E, No Deck Properties with Full Additional Dead Load

	Bridge G1697S Stresses (psi)							
LENGTH (ft)	DL+PS+ADL				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	255	t	112	t	3.605	t	1.583	t
13.2	-3420	c	241	t	0.683	c	3.403	t
26.4	-4837	c	445	t	0.966	c	6.283	t
39.6	-5208	c	501	t	1.040	c	7.083	t
52.8	-5392	c	505	t	1.077	c	7.142	t
66	130	t	290	t	1.834	t	4.104	t
79.2	-5388	c	505	t	1.077	c	7.142	t
92.4	-5202	c	499	t	1.039	c	7.059	t
105.6	-4833	c	439	t	0.966	c	6.204	t
118.8	-3431	c	232	t	0.685	c	3.279	t
132	233	t	202	t	3.293	t	2.850	t

	Bridge I1301E Stresses (psi)							
LENGTH (ft)	DL+PS+ADL				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	266	t	476	t	3.492	t	6.246	t
18	-3675	c	1171	t	0.633	c	15.376	t
36	-4218	c	913	t	0.727	c	11.986	t
54	-4213	c	874	t	0.726	c	11.480	t
72	-4558	c	761	t	0.786	c	9.997	t
90	-4721	c	729	t	0.814	c	9.571	t
108	-4567	c	768	t	0.787	c	10.084	t
126	-4190	c	871	t	0.722	c	11.432	t
144	-4072	c	838	t	0.702	c	11.005	t
162	-3600	c	749	t	0.620	c	9.833	t
180	337	t	776	t	4.423	t	10.191	t

Table 3.3: Variable Amounts of Deck Removal Using Bridge G1697S

a) Stress Values

LENGTH (ft)	Dead Load + Prestress + Additonal Prestress											
	100% DECK REMOVAL (psi)				90% DECK REMOVAL (psi)				80% DECK REMOVAL (psi)			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	284	t	113	t	1	t	125	t	-394	c	131	t
13.2	-987	c	-1707	c	-1000	c	-1702	c	47	t	-1771	c
26.4	-1022	c	-2294	c	-1034	c	-2282	c	-1080	c	-2232	c
39.6	-936	c	-2242	c	-952	c	-2235	c	-1011	c	-2202	c
52.8	-887	c	-2233	c	-899	c	-2227	c	-969	c	-2200	c
66	-714	c	-1571	c	-722	c	-1566	c	-758	c	-1545	c
79.2	-900	c	-2235	c	-915	c	-2229	c	-974	c	-2202	c
92.4	-929	c	-2250	c	-948	c	-2242	c	-1017	c	-2210	c
105.6	-997	c	-2333	c	-1000	c	-2321	c	-1063	c	-2276	c
118.8	-988	c	-1778	c	-1014	c	-1770	c	53	t	-1835	c
132	302	t	193	t	64	t	310	t	66	t	340	t

b) Stress Ratios

LENGTH (ft)	Dead Load + Prestress + Additonal Prestress											
	100% DECK REMOVAL				90% DECK REMOVAL				80% DECK REMOVAL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.021	t	1.594	t	0.019	t	1.760	t	0.079	c	1.856	t
13.2	0.197	c	0.341	c	0.200	c	0.340	c	0.664	t	0.354	c
26.4	0.204	c	0.458	c	0.207	c	0.456	c	0.216	c	0.446	c
39.6	0.187	c	0.448	c	0.190	c	0.446	c	0.202	c	0.440	c
52.8	0.177	c	0.446	c	0.180	c	0.445	c	0.194	c	0.440	c
66	0.143	c	0.314	c	0.144	c	0.313	c	0.151	c	0.309	c
79.2	0.180	c	0.447	c	0.183	c	0.445	c	0.195	c	0.440	c
92.4	0.186	c	0.450	c	0.189	c	0.448	c	0.203	c	0.442	c
105.6	0.199	c	0.466	c	0.200	c	0.464	c	0.212	c	0.455	c
118.8	0.197	c	0.355	c	0.203	c	0.354	c	0.747	t	0.367	c
132	4.272	t	2.725	t	0.908	t	4.376	t	0.931	t	4.803	t

a) Stress Values

LENGTH (ft)	Dead Load + Prestress + Additonal Prestress											
	70% DECK REMOVAL (psi)				60% DECK REMOVAL (psi)				50% DECK REMOVAL (psi)			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	1	t	125	t	5	t	122	t	7	t	121	t
13.2	-455	c	-1853	c	-509	c	-1873	c	-526	c	-1858	c
26.4	-1149	c	-2167	c	71	t	-2150	c	-442	c	-2311	c
39.6	-1087	c	-2159	c	-1237	c	-2073	c	-1391	c	-1995	c
52.8	-1055	c	-2165	c	-1216	c	-2095	c	-1370	c	-2025	c
66	-805	c	-1522	c	-899	c	-1478	c	-992	c	-1434	c
79.2	-1051	c	-2166	c	-1204	c	-2097	c	-1361	c	-2027	c
92.4	-1100	c	-2168	c	-1254	c	-2084	c	-1409	c	-2000	c
105.6	-1159	c	-2213	c	75	t	-2192	c	-455	c	-2362	c
118.8	-468	c	-1917	c	-529	c	-1935	c	-541	c	-1920	c
132	69	t	338	t	72	t	339	t	73	t	341	t

b) Stress Ratios

LENGTH (ft)	Dead Load + Prestress + Additonal Prestress											
	70% DECK REMOVAL				60% DECK REMOVAL				50% DECK REMOVAL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.016	t	1.770	t	0.069	t	1.722	t	0.099	t	1.714	t
13.2	0.091	c	0.370	c	0.102	c	0.374	c	0.105	c	0.371	c
26.4	0.230	c	0.433	c	1.005	t	0.430	c	0.088	c	0.462	c
39.6	0.217	c	0.431	c	0.247	c	0.414	c	0.278	c	0.399	c
52.8	0.211	c	0.432	c	0.243	c	0.419	c	0.274	c	0.405	c
66	0.161	c	0.304	c	0.180	c	0.295	c	0.198	c	0.286	c
79.2	0.210	c	0.433	c	0.240	c	0.419	c	0.272	c	0.405	c
92.4	0.220	c	0.433	c	0.251	c	0.416	c	0.281	c	0.400	c
105.6	0.232	c	0.442	c	1.060	t	0.438	c	0.091	c	0.472	c
118.8	0.093	c	0.383	c	0.106	c	0.387	c	0.108	c	0.384	c
132	0.974	t	4.784	t	1.017	t	4.797	t	1.031	t	4.814	t

$f'_{c\,@\,28\,days} = 4550$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,day}$

$f'_c = 5005$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

Table 3.4a: Variable Amounts of Additional Prestress Using Bridge G1697S

a) Stress Values

	600 Kips of Additional Prestress											
LENGTH	DL+PS+ADL+APS (psi)				APS (psi)				DL+PS+ADL (psi)			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	279	t	102	t	62	t	146	t	217	t	-43	c
13.2	-1890	c	-1198	c	524	t	-993	c	-2415	c	-205	c
26.4	-2814	c	-1327	c	502	t	-1196	c	-3315	c	-131	c
39.6	-3162	c	-1251	c	483	t	-1131	c	-3646	c	-120	c
52.8	-3378	c	-1210	c	469	t	-1097	c	-3847	c	-113	c
66	55	t	-769	c	465	t	-764	c	-409	c	-5	c
79.2	-3386	c	-1209	c	469	t	-1097	c	-3855	c	-111	c
92.4	-3176	c	-1250	c	487	t	-1133	c	-3663	c	-117	c
105.6	-2800	c	-1336	c	505	t	-1215	c	-3305	c	-120	c
118.8	-1882	c	-1233	c	533	t	-1027	c	-2415	c	-206	c
132	287	t	201	t	62	t	109	t	225	t	92	t

b) Stress Ratios

	600 Kips of Additional Prestress											
LENGTH	DL+PS+ADL+APS				APS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.949	t	1.442	t	0.879	t	2.057	t	3.070	t	0.009	c
13.2	0.378	c	0.239	c	7.411	t	0.198	c	0.482	c	0.041	c
26.4	0.562	c	0.265	c	7.090	t	0.239	c	0.662	c	0.026	c
39.6	0.632	c	0.250	c	6.830	t	0.226	c	0.728	c	0.024	c
52.8	0.675	c	0.242	c	6.630	t	0.219	c	0.769	c	0.023	c
66	0.784	t	0.154	c	6.568	t	0.153	c	0.082	c	0.001	c
79.2	0.676	c	0.242	c	6.629	t	0.219	c	0.770	c	0.022	c
92.4	0.635	c	0.250	c	6.881	t	0.226	c	0.732	c	0.023	c
105.6	0.559	c	0.267	c	7.131	t	0.243	c	0.660	c	0.024	c
118.8	0.376	c	0.246	c	7.531	t	0.205	c	0.483	c	0.041	c
132	4.056	t	2.842	t	0.876	t	1.543	t	3.181	t	1.299	t

a) Stress Values

	650 Kips of Additional Prestress											
LENGTH	DL+PS+ADL+APS (psi)				APS (psi)				DL+PS+ADL (psi)			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	281	t	101	t	67	t	158	t	214	t	-57	c
13.2	-1771	c	-1285	c	568	t	-1075	c	-2339	c	-209	c
26.4	-2657	c	-1430	c	543	t	-1296	c	-3200	c	-134	c
39.6	-2999	c	-1347	c	523	t	-1226	c	-3522	c	-121	c
52.8	-3217	c	-1302	c	508	t	-1189	c	-3725	c	-113	c
66	50	t	-833	c	503	t	-827	c	-453	c	-6	c
79.2	-3226	c	-1301	c	508	t	-1189	c	-3734	c	-112	c
92.4	-3014	c	-1346	c	527	t	-1227	c	-3542	c	-119	c
105.6	-2642	c	-1439	c	547	t	-1316	c	-3189	c	-123	c
118.8	-1762	c	-1324	c	577	t	-1112	c	-2340	c	-212	c
132	291	t	201	t	67	t	118	t	224	t	83	t

b) Stress Ratios

	650 Kips of Additional Prestress											
LENGTH	DL+PS+ADL+APS				APS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.979	t	1.428	t	0.952	t	2.228	t	3.027	t	0.011	c
13.2	0.354	c	0.257	c	8.029	t	0.215	c	0.467	c	0.042	c
26.4	0.531	c	0.286	c	7.681	t	0.259	c	0.639	c	0.027	c
39.6	0.599	c	0.269	c	7.400	t	0.245	c	0.704	c	0.024	c
52.8	0.643	c	0.260	c	7.183	t	0.238	c	0.744	c	0.023	c
66	0.712	t	0.166	c	7.115	t	0.165	c	0.091	c	0.001	c
79.2	0.645	c	0.260	c	7.182	t	0.238	c	0.746	c	0.022	c
92.4	0.602	c	0.269	c	7.454	t	0.245	c	0.708	c	0.024	c
105.6	0.528	c	0.288	c	7.726	t	0.263	c	0.637	c	0.025	c
118.8	0.352	c	0.265	c	8.159	t	0.222	c	0.467	c	0.042	c
132	4.119	t	2.837	t	0.949	t	1.671	t	3.171	t	1.166	t

Table 3.4b: Variable Amounts of Additional Prestress Using Bridge G1697S

a) Stress Values

LENGTH (ft)	DL+PS+ADL+APS (psi)				APS (psi)				DL+PS+ADL (psi)			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	284	t	100	t	73	t	170	t	211	t	-70	c
13.2	-1652	c	-1372	c	612	t	-1158	c	-2264	c	-214	c
26.4	-2500	c	-1533	c	585	t	-1395	c	-3086	c	-137	c
39.6	-2835	c	-1443	c	564	t	-1320	c	-3399	c	-123	c
52.8	-3056	c	-1394	c	547	t	-1280	c	-3604	c	-114	c
66	45	t	-900	c	542	t	-891	c	-497	c	-9	c
79.2	-3066	c	-1392	c	547	t	-1280	c	-3613	c	-112	c
92.4	-2852	c	-1441	c	568	t	-1322	c	-3420	c	-120	c
105.6	-2484	c	-1548	c	589	t	-1418	c	-3073	c	-130	c
118.8	-1642	c	-1415	c	622	t	-1198	c	-2264	c	-217	c
132	296	t	200	t	72	t	127	t	224	t	73	t

) Stress Ratios

LENGTH (ft)	700 Kips of Additional Prestress											
	DL+PS+ADL+APS				APS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.009	t	1.414	t	1.025	t	2.400	t	2.984	t	0.014	c
13.2	0.330	c	0.274	c	8.647	t	0.231	c	0.452	c	0.043	c
26.4	0.500	c	0.306	c	8.271	t	0.279	c	0.616	c	0.027	c
39.6	0.566	c	0.288	c	7.969	t	0.264	c	0.679	c	0.024	c
52.8	0.611	c	0.279	c	7.735	t	0.256	c	0.720	c	0.023	c
66	0.641	t	0.180	c	7.663	t	0.178	c	0.099	c	0.002	c
79.2	0.613	c	0.278	c	7.734	t	0.256	c	0.722	c	0.022	c
92.4	0.570	c	0.288	c	8.028	t	0.264	c	0.683	c	0.024	c
105.6	0.496	c	0.309	c	8.320	t	0.283	c	0.614	c	0.026	c
118.8	0.328	c	0.283	c	8.787	t	0.239	c	0.452	c	0.043	c
132	4.182	t	2.833	t	1.022	t	1.800	t	3.161	t	1.033	t

a) Stress Values

LENGTH (ft)	750 Kips of Additional Prestress											
	DL+PS+ADL+APS (psi)				APS (psi)				DL+PS+ADL (psi)			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	286	t	99	t	78	t	182	t	208	t	-83	c
13.2	-1533	c	-1459	c	655	t	-1241	c	-2188	c	-218	c
26.4	-2344	c	-1654	c	627	t	-1495	c	-2971	c	-159	c
39.6	-2674	c	-1538	c	604	t	-1414	c	-3278	c	-124	c
52.8	-2896	c	-1486	c	586	t	-1372	c	-3482	c	-114	c
66	40	t	-979	c	581	t	-954	c	-541	c	-24	c
79.2	-2906	c	-1484	c	586	t	-1372	c	-3493	c	-112	c
92.4	-2690	c	-1537	c	608	t	-1416	c	-3298	c	-121	c
105.6	-2326	c	-1682	c	631	t	-1519	c	-2957	c	-163	c
118.8	-1522	c	-1507	c	666	t	-1284	c	-2188	c	-224	c
132	300	t	200	t	77	t	136	t	223	t	64	t

) Stress Ratios

LENGTH (ft)	750 Kips of Additional Prestress											
	DL+PS+ADL+APS				APS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.039	t	1.399	t	1.099	t	2.571	t	2.941	t	0.017	c
13.2	0.306	c	0.291	c	9.264	t	0.248	c	0.437	c	0.044	c
26.4	0.468	c	0.331	c	8.862	t	0.299	c	0.594	c	0.032	c
39.6	0.534	c	0.307	c	8.538	t	0.283	c	0.655	c	0.025	c
52.8	0.579	c	0.297	c	8.288	t	0.274	c	0.696	c	0.023	c
66	0.569	t	0.196	c	8.210	t	0.191	c	0.108	c	0.005	c
79.2	0.581	c	0.297	c	8.286	t	0.274	c	0.698	c	0.022	c
92.4	0.537	c	0.307	c	8.601	t	0.283	c	0.659	c	0.024	c
105.6	0.465	c	0.336	c	8.914	t	0.304	c	0.591	c	0.033	c
118.8	0.304	c	0.301	c	9.414	t	0.256	c	0.437	c	0.045	c
132	4.246	t	2.829	t	1.095	t	1.928	t	3.151	t	0.900	t

Table 3.5: Variable Amounts of Anchorage Distance Using Bridge G1697S

a) Stress Values

	Stresses for a Constant Prestress of 500 KIPS (psi)											
	Distance from the End of the Abudment to the Additional Prestressing Anchor											
LENGTH	0 FT (psi)				5.66 FT (psi)				11.31 FT (psi)			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	350	t	639	t	274	t	106	t	266	t	110	t
13.2	-1204	c	-1643	c	-1483	c	-1793	c	-2455	c	-898	c
26.4	-1510	c	-1731	c	-1875	c	-1585	c	-1896	c	-1634	c
39.6	-1471	c	-1744	c	-1783	c	-1607	c	-1795	c	-1611	c
52.8	-1448	c	-1746	c	-1706	c	-1630	c	-1710	c	-1625	c
66	-1080	c	-1217	c	-1226	c	-1154	c	-1237	c	-1152	c
79.2	-1517	c	-1712	c	-1696	c	-1631	c	-1706	c	-1626	c
92.4	-1616	c	-1675	c	-1763	c	-1613	c	-1782	c	-1615	c
105.6	-1740	c	-1645	c	-1856	c	-1614	c	-1884	c	-1653	c
118.8	-1475	c	-1616	c	-1478	c	-1877	c	-2450	c	-875	c
132	311	t	216	t	284	t	194	t	260	t	193	t

b) Stress Ratios

	Stresses for a Constant Prestress of 500 KIPS											
	Distance from the End of the Abudment to the Additional Prestressing Anchor											
LENGTH	0 FT				5.66 FT				11.31 FT			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.954	t	9.027	t	3.878	t	1.495	t	3.765	t	1.560	t
13.2	0.241	c	0.328	c	0.296	c	0.358	c	0.490	c	0.179	c
26.4	0.302	c	0.346	c	0.375	c	0.317	c	0.379	c	0.327	c
39.6	0.294	c	0.348	c	0.356	c	0.321	c	0.359	c	0.322	c
52.8	0.289	c	0.349	c	0.341	c	0.326	c	0.342	c	0.325	c
66	0.216	c	0.243	c	0.245	c	0.231	c	0.247	c	0.230	c
79.2	0.303	c	0.342	c	0.339	c	0.326	c	0.341	c	0.325	c
92.4	0.323	c	0.335	c	0.352	c	0.322	c	0.356	c	0.323	c
105.6	0.348	c	0.329	c	0.371	c	0.323	c	0.376	c	0.330	c
118.8	0.295	c	0.323	c	0.295	c	0.375	c	0.489	c	0.175	c
132	4.398	t	3.059	t	4.012	t	2.741	t	3.680	t	2.724	t

a) Stress Values

	Stresses for a Constant Prestress of 500 KIPS (psi)											
	Distance from the End of the Abudment to the Additional Prestressing Anchor											
LENGTH	16.97 FT (psi)				22.63 FT (psi)				28.29 FT (psi)			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	261	t	113	t	258	t	114	t	256	t	115	t
13.2	-3015	c	-592	c	-2859	c	-486	c	-2829	c	-457	c
26.4	-1847	c	-1780	c	-2340	c	-1149	c	-3607	c	-808	c
39.6	-1813	c	-1626	c	-1833	c	-1666	c	-1823	c	-1715	c
52.8	-1717	c	-1622	c	-1727	c	-1623	c	-1742	c	-1633	c
66	-1247	c	-1150	c	-1257	c	-1147	c	-1267	c	-1143	c
79.2	-1716	c	-1623	c	-1727	c	-1624	c	-1739	c	-1634	c
92.4	-1805	c	-1629	c	-1828	c	-1667	c	-1818	c	-1716	c
105.6	-1839	c	-1791	c	-2333	c	-1153	c	-3613	c	-808	c
118.8	-3010	c	-575	c	-2858	c	-473	c	-2829	c	-448	c
132	249	t	192	t	243	t	194	t	240	t	195	t

b) Stress Ratios

	Stresses for a Constant Prestress of 500 KIPS											
	Distance from the End of the Abudment to the Additional Prestressing Anchor											
LENGTH	16.97 FT				22.63 FT				28.29 FT			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.695	t	1.593	t	3.654	t	1.615	t	3.625	t	1.628	t
13.2	0.602	c	0.118	c	0.571	c	0.097	c	0.565	c	0.091	c
26.4	0.369	c	0.356	c	0.468	c	0.230	c	0.721	c	0.161	c
39.6	0.362	c	0.325	c	0.366	c	0.333	c	0.364	c	0.343	c
52.8	0.343	c	0.324	c	0.345	c	0.324	c	0.348	c	0.326	c
66	0.249	c	0.230	c	0.251	c	0.229	c	0.253	c	0.228	c
79.2	0.343	c	0.324	c	0.345	c	0.324	c	0.347	c	0.326	c
92.4	0.361	c	0.325	c	0.365	c	0.333	c	0.363	c	0.343	c
105.6	0.367	c	0.358	c	0.466	c	0.230	c	0.722	c	0.161	c
118.8	0.601	c	0.115	c	0.571	c	0.095	c	0.565	c	0.089	c
132	3.514	t	2.719	t	3.438	t	2.740	t	3.392	t	2.757	t

$f'_{c\,@\,28\,days} = 4550$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 5005$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

Table 3.6: Summary Results for Bridge G1697S

a) Stress Values

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
LENGTH	DL+PS				DL+PS+APS(Jacking Force)				DL+PS+APS(Effective Force)+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	252	t	115	t	287	t	130	t	287	t	99	t
13.2	-2804	c	-435	c	-841	c	-1834	c	-1478	c	-1501	c
26.4	-3372	c	-560	c	-829	c	-2456	c	-2272	c	-1715	c
39.6	-3264	c	-643	c	-744	c	-2390	c	-2603	c	-1582	c
52.8	-3210	c	-694	c	-713	c	-2374	c	-2822	c	-1528	c
66	-2117	c	-445	c	-599	c	-1668	c	38	t	-1015	c
79.2	-3212	c	-694	c	-727	c	-2376	c	-2833	c	-1526	c
92.4	-3268	c	-642	c	-754	c	-2399	c	-2615	c	-1581	c
105.6	-3368	c	-559	c	-802	c	-2499	c	-2253	c	-1744	c
118.8	-2806	c	-432	c	-858	c	-1908	c	-1467	c	-1556	c
132	235	t	196	t	308	t	192	t	302	t	200	t

b) Stress Ratios

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
LENGTH	DL+PS				DL+PS+APS(Jacking Force)				DL+PS+APS(Effective Force)+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.569	t	1.633	t	4.058	t	1.832	t	4.053	t	1.393	t
13.2	0.560	c	0.087	c	0.168	c	0.366	c	0.295	c	0.300	c
26.4	0.674	c	0.112	c	0.166	c	0.491	c	0.454	c	0.343	c
39.6	0.652	c	0.128	c	0.149	c	0.478	c	0.520	c	0.316	c
52.8	0.641	c	0.139	c	0.142	c	0.474	c	0.564	c	0.305	c
66	0.423	c	0.089	c	0.120	c	0.333	c	0.536	t	0.203	c
79.2	0.642	c	0.139	c	0.145	c	0.475	c	0.566	c	0.305	c
92.4	0.653	c	0.128	c	0.151	c	0.479	c	0.523	c	0.316	c
105.6	0.673	c	0.112	c	0.160	c	0.499	c	0.450	c	0.348	c
118.8	0.561	c	0.086	c	0.171	c	0.381	c	0.293	c	0.311	c
132	3.326	t	2.769	t	4.350	t	2.720	t	4.275	t	2.827	t

a) Stress Values

	FULL 100% REPLACEMENT OF THE DECK							
	No Stage in Construction (psi)				Stage 4 (psi)			
LENGTH	APS(Effective Force)				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	80	t	187	t	207	t	-89	c
13.2	676	t	-1279	c	-2154	c	-222	c
26.4	646	t	-1541	c	-2918	c	-174	c
39.6	623	t	-1458	c	-3225	c	-125	c
52.8	604	t	-1414	c	-3426	c	-114	c
66	599	t	-984	c	-561	c	-31	c
79.2	604	t	-1414	c	-3437	c	-112	c
92.4	627	t	-1459	c	-3242	c	-122	c
105.6	650	t	-1566	c	-2903	c	-178	c
118.8	686	t	-1323	c	-2154	c	-233	c
132	80	t	141	t	223	t	59	t

$f'_{c\,@\,28\,days} = 4550$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 5005$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

b) Stress Ratios

	FULL 100% REPLACEMENT OF THE DECK							
	No Stage in Construction				Stage 4			
LENGTH	APS(Effective Force)				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	1.132	t	2.650	t	2.921	t	0.018	c
13.2	9.549	t	0.256	c	0.430	c	0.044	c
26.4	9.134	t	0.308	c	0.583	c	0.035	c
39.6	8.800	t	0.291	c	0.644	c	0.025	c
52.8	8.542	t	0.282	c	0.685	c	0.023	c
66	8.462	t	0.197	c	0.112	c	0.006	c
79.2	8.541	t	0.282	c	0.687	c	0.022	c
92.4	8.865	t	0.292	c	0.648	c	0.024	c
105.6	9.188	t	0.313	c	0.580	c	0.036	c
118.8	9.703	t	0.264	c	0.430	c	0.046	c
132	1.128	t	1.988	t	3.146	t	0.839	t

Table 3.7 Summary Results for Bridge I1301E

a) Stress Values

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
LENGTH	DL+PS				DL+PS+APS(Jacking Force)				DL+PS+APS(Effective Force)+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	334	t	425	t	360	t	431	t	353	t	432	t
18	-3712	c	81	t	-3082	c	-1302	c	-3628	c	-988	c
36	-3173	c	-611	c	-2598	c	-1168	c	-3509	c	-689	c
54	-2662	c	-595	c	-2137	c	-1143	c	-3301	c	-523	c
72	-2829	c	-563	c	-2258	c	-1142	c	-3638	c	-404	c
90	-2944	c	-557	c	-2371	c	-1147	c	-3808	c	-371	c
108	-2841	c	-559	c	-2253	c	-1147	c	-3615	c	-400	c
126	-2627	c	-587	c	-2096	c	-1134	c	-3252	c	-513	c
144	-3024	c	-607	c	-2450	c	-1164	c	-3346	c	-684	c
162	-3537	c	-676	c	-2933	c	-1301	c	-3438	c	-980	c
180	414	t	768	t	411	t	758	t	422	t	855	t

b) Stress Ratios

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
LENGTH	DL+PS				DL+PS+APS(Jacking Force)				DL+PS+APS(Effective Force)+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.381	t	5.583	t	4.728	t	5.659	t	4.640	t	5.677	t
18	0.640	c	1.066	t	0.531	c	0.224	c	0.625	c	0.170	c
36	0.547	c	0.105	c	0.448	c	0.201	c	0.605	c	0.119	c
54	0.459	c	0.103	c	0.368	c	0.197	c	0.569	c	0.090	c
72	0.487	c	0.097	c	0.389	c	0.197	c	0.627	c	0.070	c
90	0.507	c	0.096	c	0.409	c	0.198	c	0.656	c	0.064	c
108	0.490	c	0.096	c	0.388	c	0.198	c	0.623	c	0.069	c
126	0.453	c	0.101	c	0.361	c	0.195	c	0.560	c	0.088	c
144	0.521	c	0.105	c	0.422	c	0.201	c	0.577	c	0.118	c
162	0.609	c	0.116	c	0.505	c	0.224	c	0.592	c	0.169	c
180	5.429	t	10.076	t	5.398	t	9.953	t	5.536	t	11.225	t

a) Stress Values

	FULL 100% REPLACEMENT OF THE DECK							
	No Stage in Construction (psi)				Stage 4 (psi)			
LENGTH	APS(Effective Force)				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	65	t	87	t	288	t	345	t
18	129	t	-470	c	-3757	c	-517	c
36	115	t	-420	c	-3624	c	-268	c
54	115	t	-408	c	-3416	c	-114	c
72	109	t	-402	c	-3747	c	-2	c
90	107	t	-399	c	-3915	c	28	t
108	108	t	-401	c	-3723	c	2	t
126	114	t	-408	c	-3366	c	-104	c
144	111	t	-420	c	-3457	c	-264	c
162	130	t	-485	c	-3567	c	-495	c
180	68	t	85	t	354	t	770	t

$f'_{c\,@\,28\,days} = 5275$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 5803$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

b) Stress Ratios

	FULL 100% REPLACEMENT OF THE DECK							
	No Stage in Construction				Stage 4			
LENGTH	APS(Effective Force)				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.859	t	1.143	t	3.781	t	4.533	t
18	1.688	t	0.081	c	0.647	c	0.089	c
36	1.505	t	0.072	c	0.624	c	0.046	c
54	1.507	t	0.070	c	0.589	c	0.020	c
72	1.427	t	0.069	c	0.646	c	0.000	c
90	1.403	t	0.069	c	0.675	c	0.368	t
108	1.424	t	0.069	c	0.642	c	0.024	t
126	1.503	t	0.070	c	0.580	c	0.018	c
144	1.463	t	0.072	c	0.596	c	0.045	c
162	1.705	t	0.084	c	0.615	c	0.085	c
180	0.893	t	1.117	t	4.643	t	10.108	t

Table 3.8: Comparison of Final Stress Values Skewed and Non Skewed Bridges

a) Stess Values

Length (ft)	STAGE 4 STRESS VALUES							
	Bridge #G1697S				Bridge #I1301E			
	Stage 4 (psi)				Stage 4 (psi)			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	207	t	-89	c	288	t	345	t
13.2	-2154	c	-222	c	-3757	c	-517	c
26.4	-2918	c	-174	c	-3624	c	-268	c
39.6	-3225	c	-125	c	-3416	c	-114	c
52.8	-3426	c	-114	c	-3747	c	-2	c
66	-561	c	-31	c	-3915	c	28	t
79.2	-3437	c	-112	c	-3723	c	2	t
92.4	-3242	c	-122	c	-3366	c	-104	c
105.6	-2903	c	-178	c	-3457	c	-264	c
118.8	-2154	c	-233	c	-3567	c	-495	c
132	223	t	59	t	354	t	770	t

b) Stess Ratios

Length (ft)	COMPARISON BETWEEN FINAL STRESS VALUES									
	Bridge #G1697S				Bridge #I1301E				#G1697S / I1301E	
	Stage 4				Stage 4				Stage 4 Comparison	
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER	BOTTOM FIBER
0	2.921	t	0.018	c	3.781	t	4.533	t	0.772	0.004
18	0.430	c	0.044	c	0.647	c	0.089	c	0.665	0.497
36	0.583	c	0.035	c	0.624	c	0.046	c	0.934	0.752
54	0.644	c	0.025	c	0.589	c	0.020	c	1.095	1.266
72	0.685	c	0.023	c	0.646	c	0.000	c	1.060	60.319
90	0.112	c	0.006	c	0.675	c	0.368	t	0.166	0.017
108	0.687	c	0.022	c	0.642	c	0.024	t	1.070	0.917
126	0.648	c	0.024	c	0.580	c	0.018	c	1.117	1.351
144	0.580	c	0.036	c	0.596	c	0.045	c	0.974	0.783
162	0.430	c	0.046	c	0.615	c	0.085	c	0.700	0.545
180	3.146	t	0.839	t	4.643	t	10.108	t	0.678	0.083

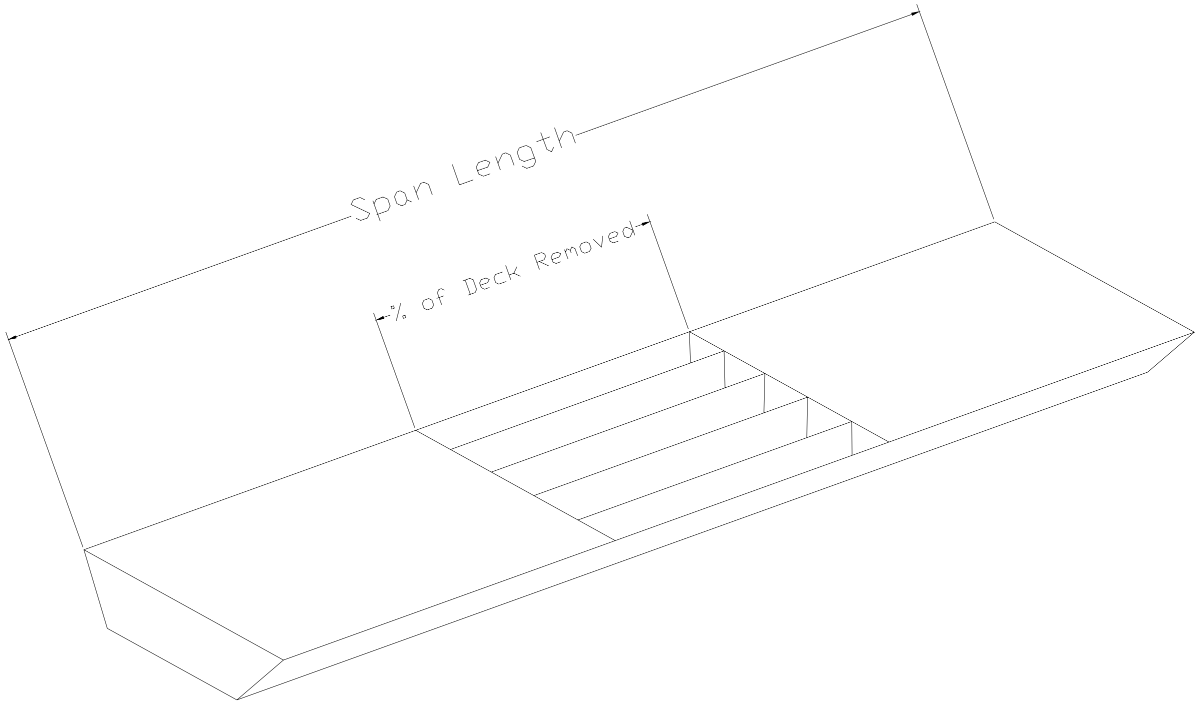


Figure 3.1: Concept of Deck Removal

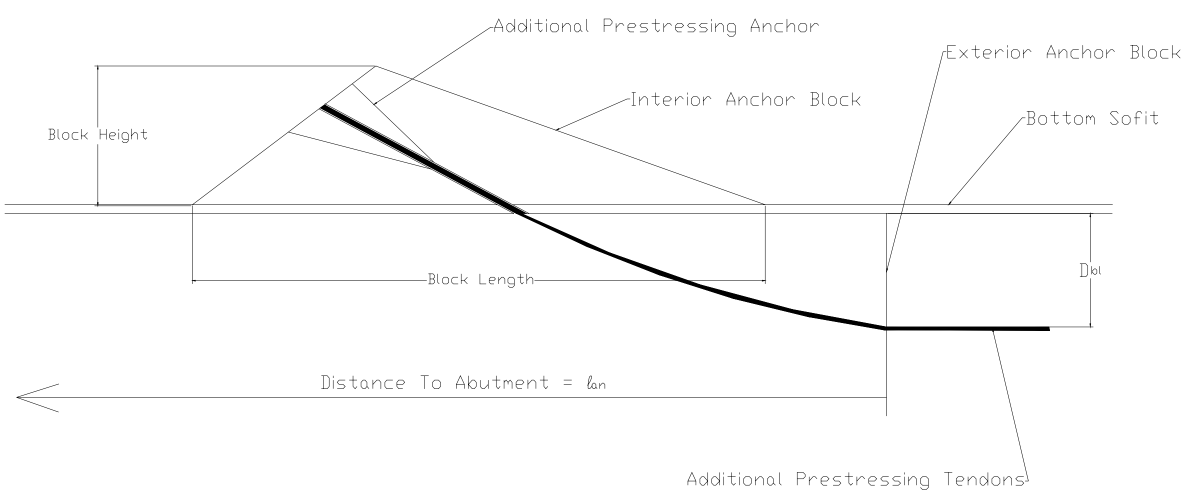


Figure 3.2: Section View of Additional Anchor and Tendon

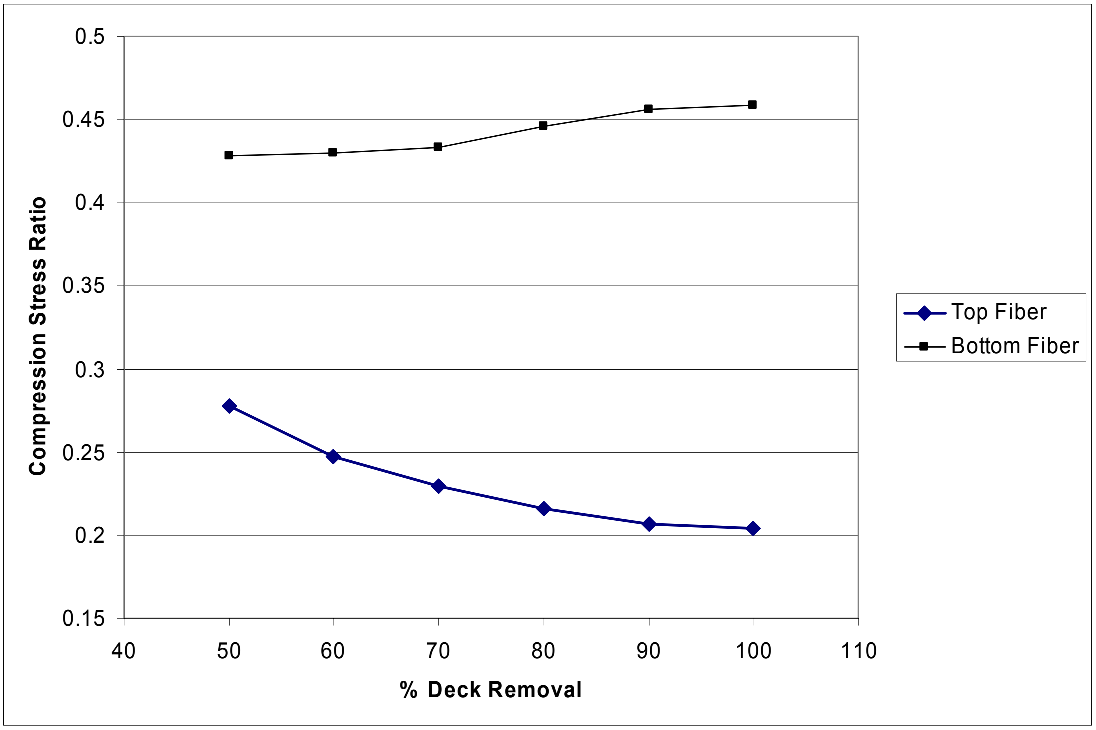


Figure 3.3: Stress Ratios for Variable Amounts of Deck Removal

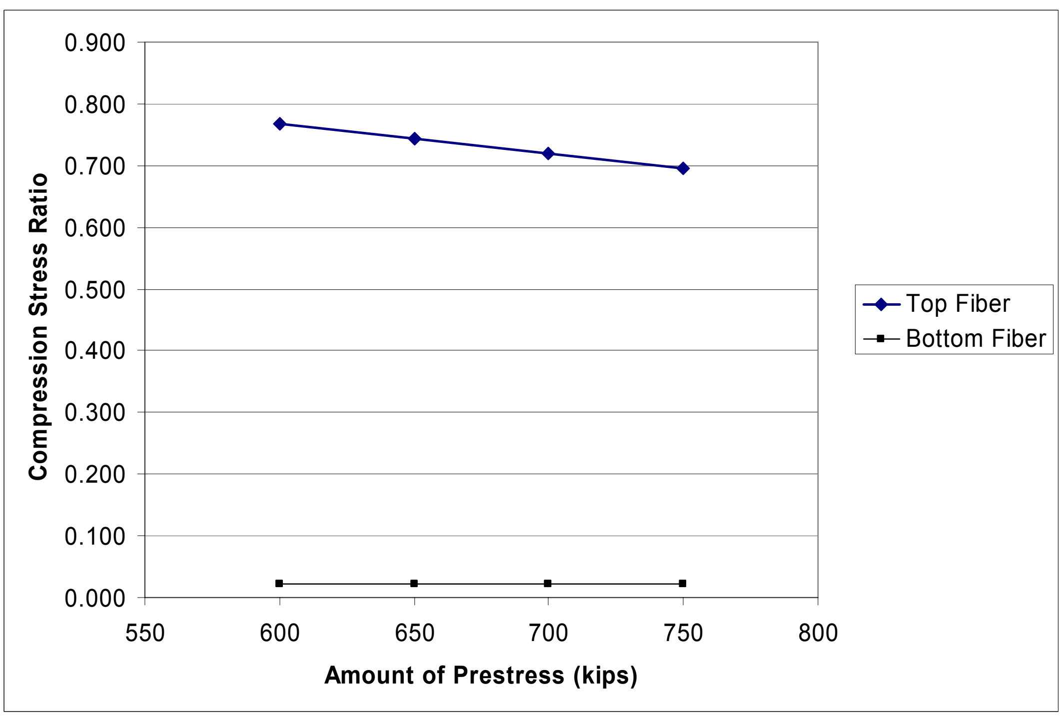


Figure 3.4: Stress Ratios for Variable Amounts of Prestress

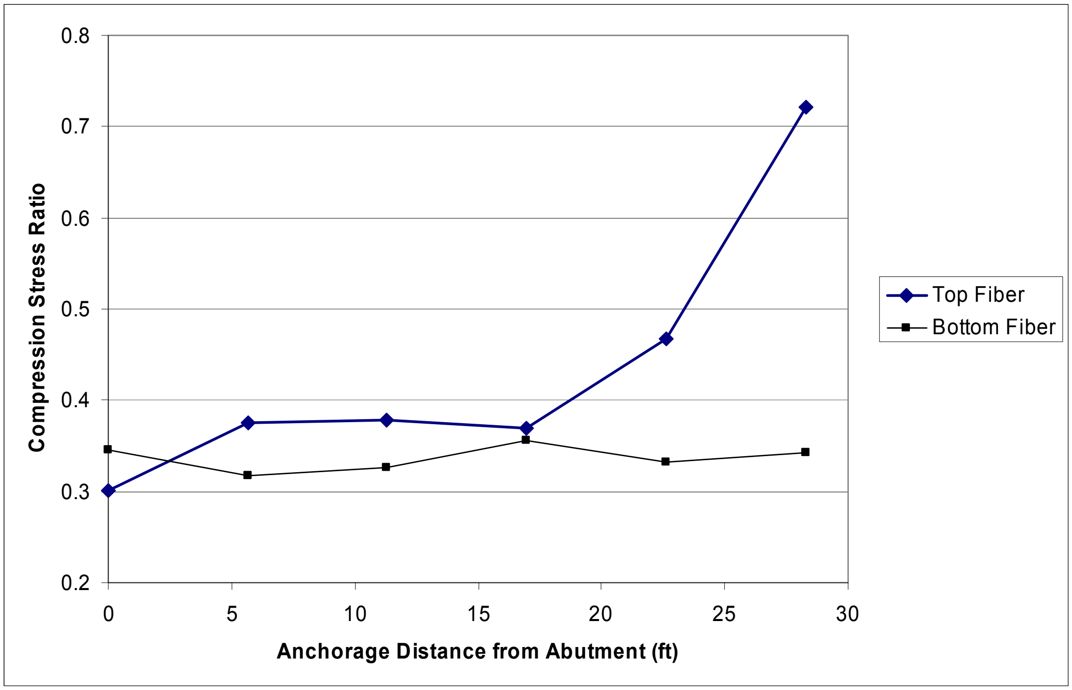


Figure 3.5: Stress Ratios for Variable Amounts of Anchor Distances

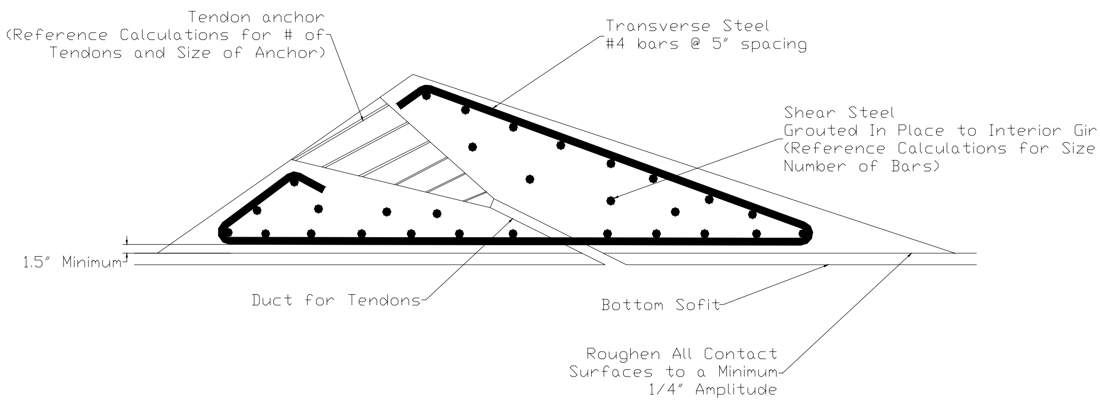


Figure 3.6: Reinforcing Steel in Additional Anchor

Chapter 4

Continuous Span Bridges and Construction Considerations

4.1 General Comments

In order to analyze the removal and replacement of continuous-span cast-in-place, post-tensioned, box-girder bridges, a two-span bridge and a three-span bridge were selected. The bridge number I871E was selected for the two-span bridge analysis and bridge number I873 was chosen for the three-span bridge analysis. The methods used to select the bridges are described in Section 2.2. These two specific bridges were believed to be a good representation of two-span and three-span bridges in Northern and Southern Nevada. As stated before in Chapter 2, Southern Nevada bridges were used because a good representation of continuous span bridges could not be obtained from using Northern Nevada bridges alone. The analysis methods used are very similar to the analysis method for simple span bridges. A 3D finite element model was built and tested using SAP 2000, and certain cases were checked using the 2D program BDS. These two programs are described in Section 2.3.

4.2 Two-Span Bridges (Bridge I871E)

Bridge I871E has two spans of 145 feet and 165 feet respectively. It has a deck width of approximately 46 feet, a 49-degree skew, and the year of construction was 1977. The correlation between the 3D and 2D analyses is shown in Table 4.1. The 3D analysis results that are summarized in the full deck properties of Table 4.1 are shown in Figures D.1 through D.4. The 3D analysis results that are summarized in the no deck properties of Table 4.1 are shown in Figures D.5 through D.8. Looking at the column "SAP 2000 /

BDS" for the full deck properties in Table 4.1, it shows that on average, the two analyses are within 10% - 20% of each other at the top and bottom fibers in span 2 and in the bottom fiber in span 1. The top fiber stresses in span 1 are within 30% - 40%. The no deck properties have further differences in the 2D and 3D analyses than the full deck properties have since the 2D analysis cannot accurately model the bottom sofit of the bridge. The 2D analysis cannot take into account the way the bottom sofit flares as the 3D case can. These differences will make a great impact on the section properties of the two analyses, and therefore, the results are different between the 2D and 3D analyses. For the simple span analysis, the bottom sofit did not flare resulting in more similar results between the 2D and 3D analyses. This stress difference will also be shown in the 3-span analysis later in Chapter 4. Also, the 3D analysis no deck case predicts tension in the top and bottom fiber over the support, where the 2D analysis no deck case yields compression in the top and bottom fiber over the support. Comparing the 2D and 3D analyses, we can see the same trends in the changing of the stresses when the top deck is removed.

The next step in the 2-span analysis was to find a possible way to remove and replace the deck. Table 4.2a and Table 4.2b shows the analysis of Bridge I871E with and without an additional prestress of 900 kips added to the bottom sofit, similar to the simple span bridge analysis. The analysis for continuous span bridges used a case where there was no additional prestress and a case where there was additional prestress. This was done to determine the impact of the additional prestress on the bottom sofit and see if it was needed. Stage 1 is when the deck has not been removed. Stage 2 happens when the full deck has been removed from the bridge. Stages 1 and 2 were compared to the 2D analysis results in Table 4.1. The tensile stresses over the support in Stage 2 reaches the maximum value of $6\sqrt{f'_c}$. Stage 3 is when the full complete deck is replaced with no additional prestressing. Looking at the stresses over the supports at Stage 3, the values well exceed the maximum value of $6\sqrt{f'_c}$ up to $18.26\sqrt{f'_c}$. With a tensile stress in the elastic material of $18.26\sqrt{f'_c}$, this is well above the cracking stress of concrete. The analysis is not valid at this point, but it does indicate that the cracking would be too severe to permit. Therefore, without some exterior force on the bridge, the full deck cannot be replaced after removal. Stage 3 alternative is when an additional prestressing force has been added to the bottom sofit before the deck has been replaced. For this analysis an additional prestressing force of 750 kips per girder was used, also similar to the simple span version of the analysis. Unfortunately, comparing Stage 2 and Stage 3 alternatives, an additional prestressing force barely helps the tensile stresses over the support. Stage 4 is when the full deck has been replaced with the additional prestressing force. Looking at the stresses over the support, the final stresses yield $17.74\sqrt{f'_c}$, which is close to the Stage 3 version when the deck has been fully replaced with no additional prestress. Additional prestressing was also placed inside the girder. Placing the prestressing inside the girder did not lower the stresses over the support. For continuous span bridges, it is obvious that adding an additional prestressing force will barely influence the tensile stresses over the support. One positive note is, because of the stiffness of the bridge, the compression stresses never exceed the maximum value of 0.70 f'_c. In analyzing the data, the most cost-effective solution in replacing continuous span bridge decks is shoring of the bottom sofit after removal but before replacement of the deck. The shoring of the deck would be designed for the additional load of the "wet soggy" deck. This would account for any additional load that the deck would induce. There is some uncertainty in the analysis as to the impact of the high tensile stresses. The analysis does not provide for cracking. The cracking would cause a change in section properties. The cracks could be closed by the removal of the additional prestress.

4.3 Three-Span Bridges (Bridge I873)

Bridge I873 has three spans of 60 feet, 160 feet, and 60 feet respectively. It has a deck with of approximately 39 feet, a 15 degree skew, and the year of construction was 1979. The correlation between the 3D and 2D analyses is shown in Table 4.3. Looking at the column "SAP 2000 / BDS" in Table 4.3, it shows that, on average, the two analyses are within 20% difference of each other. The 3D analysis results that are summarized in the full deck properties of Table 4.3 are shown in Figures D.21 through D.26. The 3D analysis results that are summarized in the no deck properties of Table 4.3 are shown in Figures D.27 through D.32. The two sets of data show that the 2D and 3D analysis results yield compression at the same span length with very similar numbers. The exception is that the 3D analysis yields tension in the top and bottom fiber over the supports where the 2D analysis yields compression in the top and bottom fiber over the supports.

The next step in the 3-span analysis was to find a possible way to remove and replace the deck, similar to the 2-span continuous analysis. Table 4.4a and Table 4.4b show the analysis of Bridge I873 with no additional prestress as well as with additional prestress added to the bottom sofit, similar to the 2-span continuous bridge analysis. Stage 1 is when the deck has not been removed. Stage 2 happens when the full deck has been removed from the 3-span bridge. Stages 1 and 2 can also be compared to the 2D analysis results in Table 4.3. The tensile stresses over the support in Stage 2 reaches maximum stress value of $6\sqrt{f'_c}$. It actually gets to a maximum of $6.62\sqrt{f'_c}$. Stage 3 is when the full complete deck is replaced with no additional prestressing. Looking at the stresses over the supports at Stage 3, the values exceed the maximum value of $6\sqrt{f'_c}$ and reach a maximum value of $9.46\sqrt{f'_c}$. Therefore, exterior shoring or prestressing is needed to remove and replace the deck, because the stresses are over the maximum code values. Stage 3 alternative is when an additional prestressing force has been added to the bottom sofit before the deck has been replaced. This analysis was conducted to see if the additional prestressing would produce a significant difference in the end result for a 3-span continuous bridge. For this analysis, an additional prestressing force of 750 kips per girder was used, also similar to the 2-span continuous version of the analysis. Comparing Stage 2 and Stage 3 alternative, an additional prestressing force barely helps the tensile stresses over the support, similar to the 2-span analysis. Stage 4 is when the full deck has been replaced with the additional prestressing force. Looking at the stresses over the support, the final stresses yield $6.23\sqrt{f'_c}$, which is still close to the Stage 3 version when the deck has been fully replaced with no additional prestress. For continuous span bridges, it is obvious that adding an additional prestressing force will barely influence the tensile stresses over the support. By analyzing the 2-span and 3-span continuous bridges with an additional prestress, it shows that the impact of additional prestressing is minimal. We have shown that continuous span bridges will have to be analyzed on a case-by-case basis.

4.4 Conclusion for Continuous Span Bridges

No equations can be evaluated when removing and replacing the bridge deck for continuous bridges. In this case, a 2D or even a 3D analysis of the bridge will have to be conducted. A 2D analysis might be adequate, but some localized stresses will have to be evaluated that will only show up in the 3D analysis case. The 2D analysis done for this project was very simplified. A more detailed 2D analysis should be sufficient since skew effects were small.

4.5 Traffic Analysis of Construction Site

Removal and replacement of cast-in-place, post-tensioned, box-girder bridge decks will have to be evaluated on a case-by-case basis. As it has already been discussed with continuous-span bridge decks, it will also have to be evaluated for simple-span bridge decks.

Such cases where only one bridge exists, and traffic cannot be rerouted or detoured with an alternate route, a new bridge will have to be built next to the one in question, due to traffic control. After a new bridge has been built, it will then be possible to remove the deck of the older bridge by rerouting traffic onto the new bridge.

The bridges were analyzed with only half of the deck removed at a time. This produced high torsional forces at the end abutments. These additional forces were evaluated to be a negative influence on the bridge.

If two bridges exist side-by-side of each other, it is very possible to remove and replace the bridge decks. It is possible to route both lanes of traffic through one bridge, while the deck is being replaced. After the one deck has been replaced, it is then possible to route traffic through the other side. Then the second bridge deck may be removed and replaced.

During the actual construction phase of removal and replacement of the bridge decks, traffic control underneath the bridge will not be a problem. Since additional prestressing will be used, this will not inhibit traffic under bridges, and will not restrict the length of the bridge being replaced. Height restriction will need to be placed on trucks.

4.6 Possible Design Considerations of Bridges

At this point in time, no design considerations have been noticed in the removal and replacement of cast-in-place, post-tensioned, box-girder bridge decks. It would be useful if the bridge was checked without the deck in the initial design. This may control different section properties needed that will be useful in the future maintenance of the bridge.

It is possible to place empty ducts at the bottom of the girders or sofit in new bridge construction, but the eccentricity would not be enough when the deck is removed. To design for this small eccentricity, a large prestressing force would be needed. This is not an economical way to design the additional prestressing tendons and anchors.

Table 4.1: Comparison of 3D and 2D Analysis of Bridge 1871E

	Full Deck Properties						
	Bridge I871E					SAP 2000 / BDS	
	Length	SAP 2000 (psi)		BDS (psi)			
	(ft)	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber
Span 1	0	-680	-433	-687	-699	0.990	0.620
	14.5	-1109	-1078	-885	-1031	1.254	1.046
	29	-1205	-1074	-888	-1129	1.357	0.951
	43.5	-1199	-1042	-845	-1201	1.419	0.867
	58	-1070	-1055	-788	-1292	1.358	0.816
	72.5	-962	-1090	-719	-1397	1.338	0.781
	87	-902	-1179	-692	-1459	1.303	0.808
	101.5	-891	-1171	-768	-1393	1.161	0.840
	116	-923	-1124	-950	-1184	0.972	0.949
	130.5	-1105	-878	-1228	-672	0.900	1.306
	145	-878	-1409	-1070	-647	0.821	2.178
Span 2	0	-878	-1409	-944	-766	0.930	1.839
	16.5	-1126	-905	-1249	-675	0.902	1.341
	33	-1010	-1051	-1094	-1007	0.923	1.044
	49.5	-998	-1164	-1003	-1120	0.995	1.039
	66	-1081	-1021	-984	-1116	1.099	0.915
	82.5	-1131	-940	-1038	-1021	1.090	0.921
	99	-1188	-857	-1106	-918	1.075	0.934
	115.5	-1288	-893	-1131	-868	1.139	1.028
	132	-1258	-989	-1112	-873	1.131	1.133
	148.5	-1161	-1084	-1047	-936	1.108	1.158
	165	-939	-454	-695	-707	1.352	0.642

	No Deck Properties						
	Bridge I871E					SAP 2000 / BDS	
	Length	SAP 2000 (psi)		BDS (psi)			
	(ft)	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber	Top Fiber	Bottom Fiber
Span 1	0	244	384	-3486	57	-0.070	6.735
	14.5	-2463	-909	-3767	-304	0.654	2.991
	29	-2270	-1096	-3999	-817	0.568	1.342
	43.5	-2006	-1300	-2501	-1383	0.802	0.940
	58	-1716	-1518	-952	-1971	1.802	0.770
	72.5	-1254	-1694	-710	-1961	1.766	0.864
	87	-983	-1837	-980	-1654	1.003	1.110
	101.5	-987	-1885	-1022	-1460	0.966	1.291
	116	-1143	-1670	-1006	-1316	1.136	1.269
	130.5	-1844	-1198	-968	-1203	1.905	0.996
	145	868	-1575	-878	-1142	-0.988	1.379
Span 2	0	868	-1575	-2648	-178	-0.328	8.847
	16.5	-1632	-1254	-2716	-635	0.601	1.975
	33	-1230	-1678	-1600	-1784	0.769	0.941
	49.5	-1265	-1834	-1233	-1984	1.026	0.925
	66	-1409	-1604	-1190	-2017	1.184	0.795
	82.5	-1769	-1445	-1171	-2026	1.511	0.713
	99	-2244	-1215	-1190	-2017	1.886	0.602
	115.5	-2532	-1000	-1233	-1984	2.053	0.504
	132	-2687	-868	-1600	-1784	1.679	0.486
	148.5	-2774	-750	-2716	-635	1.021	1.182
	165	238	396	-2648	-178	-0.090	-2.224

Table 4.2a: Summary of Results for Bridge 1871E Span 1

a) Stress Values

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	-680	c	276	t	244	t	384	t	245	t	416	t
14.5	-1109	c	-1078	c	-2463	c	-909	c	-2851	c	-725	c
29	-1205	c	-1074	c	-2270	c	-1096	c	-2822	c	-814	c
43.5	-1199	c	-1042	c	-2006	c	-1300	c	-2652	c	-965	c
58	-1070	c	-1055	c	-1716	c	-1518	c	-2424	c	-1183	c
72.5	-962	c	-1090	c	-1254	c	-1694	c	-1849	c	-1416	c
87	-902	c	-1179	c	-983	c	-1837	c	-1403	c	-1674	c
101.5	-891	c	-1171	c	-987	c	-1885	c	-1201	c	-1878	c
116	-923	c	-1124	c	-1143	c	-1670	c	-934	c	-1922	c
130.5	-1105	c	-878	c	-1844	c	-1198	c	-1239	c	-1546	c
145	-878	c	-1409	c	868	t	-1575	c	1270	t	-2377	c

b) Stress Ratios

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.14	c	3.97	t	3.51	t	5.52	t	3.52	t	5.97	t
14.5	0.23	c	0.22	c	0.51	c	0.19	c	0.59	c	0.15	c
29	0.25	c	0.22	c	0.47	c	0.23	c	0.58	c	0.17	c
43.5	0.25	c	0.22	c	0.41	c	0.27	c	0.55	c	0.20	c
58	0.22	c	0.22	c	0.35	c	0.31	c	0.50	c	0.24	c
72.5	0.20	c	0.23	c	0.26	c	0.35	c	0.38	c	0.29	c
87	0.19	c	0.24	c	0.20	c	0.38	c	0.29	c	0.35	c
101.5	0.18	c	0.24	c	0.20	c	0.39	c	0.25	c	0.39	c
116	0.19	c	0.23	c	0.24	c	0.35	c	0.19	c	0.40	c
130.5	0.23	c	0.18	c	0.38	c	0.25	c	0.26	c	0.32	c
145	0.18	c	0.29	c	12.47	t	0.33	c	18.26	t	0.49	c

a) Stress Values

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative (psi)				Stage 4 (psi)			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	245	t	384	t	247	t	412	t
14.5	-2483	c	-953	c	-2833	c	-774	c
29	-2236	c	-1184	c	-2746	c	-930	c
43.5	-1929	c	-1413	c	-2560	c	-1063	c
58	-1659	c	-1618	c	-2347	c	-1276	c
72.5	-1220	c	-1780	c	-1806	c	-1502	c
87	-968	c	-1913	c	-1392	c	-1748	c
101.5	-985	c	-1949	c	-1208	c	-1940	c
116	-1147	c	-1681	c	-976	c	-1929	c
130.5	-2033	c	-1149	c	-1397	c	-1477	c
145	837	t	-1509	c	1234	t	-2289	c

b) Stress Ratios

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative				Stage 4			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.53	t	5.52	t	3.55	t	5.93	t
14.5	0.51	c	0.20	c	0.59	c	0.16	c
29	0.46	c	0.24	c	0.57	c	0.19	c
43.5	0.40	c	0.29	c	0.53	c	0.22	c
58	0.34	c	0.33	c	0.48	c	0.26	c
72.5	0.25	c	0.37	c	0.37	c	0.31	c
87	0.20	c	0.40	c	0.29	c	0.36	c
101.5	0.20	c	0.40	c	0.25	c	0.40	c
116	0.24	c	0.35	c	0.20	c	0.40	c
130.5	0.42	c	0.24	c	0.29	c	0.31	c
145	12.03	t	0.31	c	17.74	t	0.47	c

$f'_{c\,@\,28\,days} = 4400$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 4840$ psi

Compression
$\phi = f_c / f'_c$

Tension
$\phi = f_c / \sqrt{f'_c}$

Table 4.2b: Summary Results for Bridge 1871E Span 2

a) Stress Values

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
LENGTH	DL+PS				DL+PS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	-878	c	-1409	c	868	t	-1575	c	1270	t	-2377	c
16.5	-1126	c	-905	c	-1632	c	-1254	c	-987	c	-1994	c
33	-1010	c	-1051	c	-1230	c	-1678	c	-1171	c	-1917	c
49.5	-998	c	-1164	c	-1265	c	-1834	c	-1665	c	-1749	c
66	-1081	c	-1021	c	-1409	c	-1604	c	-2145	c	-1319	c
82.5	-1131	c	-940	c	-1769	c	-1445	c	-2779	c	-1056	c
99	-1188	c	-857	c	-2244	c	-1215	c	-3324	c	-828	c
115.5	-1288	c	-893	c	-2532	c	-1000	c	-3492	c	-655	c
132	-1258	c	-989	c	-2687	c	-868	c	-3568	c	-532	c
148.5	-1161	c	-1084	c	-2774	c	-750	c	-3329	c	-528	c
165	-939	c	316	t	238	t	396	t	237	t	433	t

b) Stress Ratios

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
LENGTH	DL+PS				DL+PS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.18	c	0.29	c	12.47	t	0.33	c	18.26	t	0.49	c
16.5	0.23	c	0.19	c	0.34	c	0.26	c	0.20	c	0.41	c
33	0.21	c	0.22	c	0.25	c	0.35	c	0.24	c	0.40	c
49.5	0.21	c	0.24	c	0.26	c	0.38	c	0.34	c	0.36	c
66	0.22	c	0.21	c	0.29	c	0.33	c	0.44	c	0.27	c
82.5	0.23	c	0.19	c	0.37	c	0.30	c	0.57	c	0.22	c
99	0.25	c	0.18	c	0.46	c	0.25	c	0.69	c	0.17	c
115.5	0.27	c	0.18	c	0.52	c	0.21	c	0.72	c	0.14	c
132	0.26	c	0.20	c	0.56	c	0.18	c	0.74	c	0.11	c
148.5	0.24	c	0.22	c	0.57	c	0.16	c	0.69	c	0.11	c
165	0.19	c	4.55	t	3.42	t	5.69	t	3.41	t	6.22	t

a) Stress Values

	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative (psi)				Stage 4 (psi)			
LENGTH	DL+PS+APS				DL+PS+ADL+APS			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	837	t	-1509	c	1234	t	-2289	c
16.5	-1770	c	-1218	c	-1096	c	-1743	c
33	-1262	c	-1663	c	-1213	c	-1929	c
49.5	-1263	c	-1899	c	-1676	c	-1812	c
66	-1394	c	-1681	c	-2127	c	-1394	c
82.5	-1734	c	-1530	c	-2733	c	-1128	c
99	-2175	c	-1300	c	-3245	c	-911	c
115.5	-2450	c	-1096	c	-3395	c	-755	c
132	-2631	c	-977	c	-3471	c	-657	c
148.5	-2810	c	-802	c	-3303	c	25	t
165	240	t	397	t	239	t	431	t

b) Stress Ratios

	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative				Stage 4			
LENGTH	DL+PS+APS				DL+PS+ADL+APS			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	12.03	t	0.31	c	17.74	t	0.47	c
16.5	0.37	c	0.25	c	0.23	c	0.36	c
33	0.26	c	0.34	c	0.25	c	0.40	c
49.5	0.26	c	0.39	c	0.35	c	0.37	c
66	0.29	c	0.35	c	0.44	c	0.29	c
82.5	0.36	c	0.32	c	0.56	c	0.23	c
99	0.45	c	0.27	c	0.67	c	0.19	c
115.5	0.51	c	0.23	c	0.70	c	0.16	c
132	0.54	c	0.20	c	0.72	c	0.14	c
148.5	0.58	c	0.17	c	0.68	c	0.36	t
165	3.44	t	5.70	t	3.44	t	6.20	t

$f'_{c\ @\ 28\ days} = 4400$ psi

$f'_c = 1.10 \times f'_{c\ @\ 28\ days}$

$f'_c = 4840$ psi

Compression
$\phi = f_c / f'_c$

Tension
$\phi = f_c / \sqrt{f'_c}$

Table 4.3: Comparison of 3D and 2D Analysis of Bridge 1873

Full Deck Properties

	Length (ft)	SAP 2000 (psi) Top Fiber	SAP 2000 (psi) Bottom Fiber	BDS (psi) Top Fiber	BDS (psi) Bottom Fiber	SAP 2000 / BDS Top Fiber	SAP 2000 / BDS Bottom Fiber
Span 1	0	-490	365	-762	-695	0.643	-0.526
	6	-864	-952	-775	-864	1.115	1.102
	12	-817	-1034	-775	-1107	1.055	0.934
	18	-773	-1125	-666	-1252	1.161	0.899
	24	-713	-1025	-535	-1427	1.332	0.718
	30	-672	142	-569	-1321	1.182	-0.108
	36	-636	127	-642	-1108	0.991	-0.115
	42	-617	125	-655	-988	0.942	-0.126
	48	-616	128	-646	-909	0.953	-0.141
	54	-615	167	-624	-854	0.986	-0.196
	60	-582	486	-582	-840	1.000	-0.579
Span 2	0	-582	486	-723	-663	0.805	-0.733
	16	-671	113	-895	-701	0.750	-0.161
	32	-802	35	-820	-1127	0.978	-0.031
	48	-1083	-728	-997	-936	1.086	0.777
	64	-1204	-569	-1127	-782	1.069	0.727
	80	-1232	-392	-1170	-728	1.053	0.539
	96	-1204	-569	-1127	-782	1.069	0.727
	112	-1083	-728	-997	-936	1.086	0.777
	128	-802	35	-820	-1127	0.978	-0.031
	144	-671	113	-895	-701	0.750	-0.161
	160	-582	485	-723	-663	0.804	-0.732
Span 3	0	-582	485	-582	-840	0.999	-0.578
	6	-616	168	-624	-854	0.988	-0.197
	12	-614	127	-646	-909	0.951	-0.140
	18	-616	124	-655	-988	0.940	-0.126
	24	-630	128	-642	-1108	0.982	-0.116
	30	-663	146	-569	-1321	1.165	-0.111
	36	-702	-1025	-535	-1427	1.312	0.718
	42	-764	-1104	-666	-1252	1.147	0.882
	48	-809	-978	-775	-1107	1.044	0.883
	54	-795	-832	-775	-864	1.025	0.963
	60	-394	-468	-762	-695	0.517	0.673

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No Deck Properties

	Length (ft)	SAP 2000 (psi) Top Fiber	SAP 2000 (psi) Bottom Fiber	BDS (psi) Top Fiber	BDS (psi) Bottom Fiber	SAP 2000 / BDS Top Fiber	SAP 2000 / BDS Bottom Fiber
Span 1	0	769	340	-3486	57	-0.221	5.958
	6	-2043	-636	-3767	-304	0.542	2.092
	12	-2204	-945	-3999	-817	0.551	1.156
	18	-1790	-1196	-2501	-1383	0.716	0.865
	24	-1173	-1240	-952	-1971	1.232	0.629
	30	-709	316	-710	-1961	0.998	-0.161
	36	-595	284	-980	-1654	0.607	-0.172
	42	-710	245	-1022	-1460	0.695	-0.168
	48	-876	225	-1006	-1316	0.871	-0.171
	54	-999	251	-968	-1203	1.032	-0.208
	60	328	466	-878	-1142	-0.374	-0.408
Span 2	0	328	466	-2648	-178	-0.124	-2.616
	16	-1308	213	-2716	-635	0.482	-0.336
	32	-823	144	-1600	-1784	0.514	-0.081
	48	-1245	-1204	-1233	-1984	1.010	0.607
	64	-1576	-1110	-1190	-2017	1.324	0.550
	80	-1118	-860	-1171	-2026	0.955	0.424
	96	-1575	-1110	-1190	-2017	1.324	0.550
	112	-1243	-1205	-1233	-1984	1.008	0.607
	128	-820	144	-1600	-1784	0.513	-0.081
	144	-1308	213	-2716	-635	0.482	-0.336
	160	330	466	-2648	-178	-0.125	-2.615
Span 3	0	330	466	-878	-1142	-0.376	-0.408
	6	-998	251	-968	-1203	1.031	-0.208
	12	-870	224	-1006	-1316	0.865	-0.170
	18	-704	244	-1022	-1460	0.689	-0.167
	24	-587	281	-980	-1654	0.599	-0.170
	30	-704	312	-710	-1961	0.991	-0.159
	36	-1170	-1224	-952	-1971	1.229	0.621
	42	-1792	-1189	-2501	-1383	0.717	0.859
	48	-2211	-925	-3999	-817	0.553	1.132
	54	-2075	-649	-3767	-304	0.551	2.133
	60	196	91	-3486	57	-0.056	1.594

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Table 4.4a: Summary Results for Bridge 1873 Span 1

a) Stress Values

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	434	c	365	t	769	t	340	t	759	t	348	t
6	-864	c	-952	c	-2043	c	-636	c	-2100	c	-688	c
12	-817	c	-1034	c	-2204	c	-945	c	-2304	c	-922	c
18	-773	c	-1125	c	-1790	c	-1196	c	-1870	c	-1166	c
24	-713	c	-1025	c	-1173	c	-1240	c	-1181	c	-1019	c
30	-672	c	142	c	-709	c	316	c	-605	c	436	t
36	-636	c	127	c	-595	c	284	c	-396	c	322	t
42	-617	c	125	c	-710	c	245	c	-447	c	276	t
48	-616	c	128	c	-876	c	225	c	-640	c	222	t
54	-615	c	167	c	-999	c	251	c	-733	c	264	t
60	-582	c	486	c	328	t	466	c	339	t	666	t

b) Stress Ratios

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	6.17	t	5.19	t	10.93	t	4.83	t	10.78	t	4.94	t
6	0.17	c	0.19	c	0.41	c	0.13	c	0.42	c	0.14	c
12	0.17	c	0.21	c	0.45	c	0.19	c	0.47	c	0.19	c
18	0.16	c	0.23	c	0.36	c	0.24	c	0.38	c	0.24	c
24	0.14	c	0.21	c	0.24	c	0.25	c	0.24	c	0.21	c
30	0.14	c	2.02	t	0.14	c	4.50	t	0.12	c	6.19	t
36	0.13	c	1.80	t	0.12	c	4.04	t	0.08	c	4.58	t
42	0.12	c	1.77	t	0.14	c	3.48	t	0.09	c	3.93	t
48	0.12	c	1.82	t	0.18	c	3.20	t	0.13	c	3.16	t
54	0.12	c	2.38	t	0.20	c	3.56	t	0.15	c	3.75	t
60	0.12	c	6.91	t	4.67	t	6.62	t	4.82	t	9.46	t

a) Stress Values

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative (psi)				Stage 4 (psi)			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	911	t	324	t	912	t	322	t
14.5	-2743	c	866	t	-2790	c	911	t
29	108	t	-3293	c	45	t	-3236	c
43.5	146	t	-2634	c	81	t	-2596	c
58	320	t	-1690	c	322	t	-1692	c
72.5	242	t	645	t	330	t	673	t
87	-604	c	506	t	-399	c	529	t
101.5	-967	c	419	t	-701	c	437	t
116	-1945	c	440	t	-1732	c	338	t
130.5	-1783	c	120	t	-1573	c	135	t
145	285	t	267	t	312	t	438	t

b) Stress Ratios

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative				Stage 4			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	12.95	t	4.60	t	12.96	t	4.57	t
14.5	0.55	c	12.32	t	0.56	c	12.94	t
29	1.54	t	0.67	c	0.64	t	0.65	c
43.5	2.08	t	0.53	c	1.14	t	0.52	c
58	4.55	t	0.34	c	4.57	t	0.34	c
72.5	3.44	t	9.16	t	4.70	t	9.56	t
87	0.12	c	7.19	t	0.08	c	7.52	t
101.5	0.20	c	5.95	t	0.14	c	6.21	t
116	0.39	c	6.25	t	0.35	c	4.80	t
130.5	0.36	c	1.71	t	0.32	c	1.91	t
145	4.05	t	3.80	t	4.44	t	6.23	t

$f'_{c\,@\,28\,days} = 4500$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 4950$ psi

Compression
$\phi = f_c / f'_c$

Tension
$\phi = f_c / \sqrt{f'_c}$

Table 4.4b: Summary Results for Bridge 1873 Span 2

a) Stress Values

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
LENGTH	DL+PS				DL+PS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	-582	c	486	t	328	t	466	t	339	t	666	t
16	-671	c	113	c	-1308	c	213	c	-605	c	329	t
32	-802	c	35	c	-823	c	144	c	-456	c	233	t
48	-1083	c	-728	c	-1245	c	-1204	c	-1685	c	-1176	c
64	-1204	c	-569	c	-1576	c	-1110	c	-2619	c	-933	c
80	-1232	c	-392	c	-1118	c	-860	c	-1953	c	-597	c
96	-1204	c	-569	c	-1575	c	-1110	c	-2618	c	-934	c
112	-1083	c	-728	c	-1243	c	-1205	c	-1684	c	-1177	c
128	-802	c	35	c	-820	c	144	c	-454	c	233	t
144	-671	c	113	c	-1308	c	213	c	-603	c	329	t
160	-582	c	485	c	330	t	466	c	341	t	666	t

b) Stress Ratios

	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
LENGTH	DL+PS				DL+PS				DL+PS+ADL			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.12	c	6.91	t	4.67	t	6.62	t	4.82	t	9.46	t
16	0.14	c	1.60	t	0.26	c	3.03	t	0.12	c	4.68	t
32	0.16	c	0.49	t	0.17	c	2.05	t	0.09	c	3.31	t
48	0.22	c	0.15	c	0.25	c	0.24	c	0.34	c	0.24	c
64	0.24	c	0.11	c	0.32	c	0.22	c	0.53	c	0.19	c
80	0.25	c	0.08	c	0.23	c	0.17	c	0.39	c	0.12	c
96	0.24	c	0.11	c	0.32	c	0.22	c	0.53	c	0.19	c
112	0.22	c	0.15	c	0.25	c	0.24	c	0.34	c	0.24	c
128	0.16	c	0.50	t	0.17	c	2.05	t	0.09	c	3.31	t
144	0.14	c	1.60	t	0.26	c	3.03	t	0.12	c	4.68	t
160	0.12	c	6.90	t	4.70	t	6.62	t	4.85	t	9.46	t

a) Stress Values

	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative (psi)				Stage 4 (psi)			
LENGTH	DL+PS+APS				DL+PS+ADL+APS			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	285	t	267	t	312	t	438	t
16	-2336	c	118	t	-1616	c	151	t
32	-3058	c	561	t	-2530	c	467	t
48	-1010	c	-2123	c	-1375	c	-2008	c
64	-1357	c	-1832	c	-2414	c	-1583	c
80	-915	c	-1496	c	-1728	c	-1141	c
96	-1357	c	-1833	c	-2414	c	-1583	c
112	-1010	c	-2123	c	-1374	c	-2008	c
128	-3052	c	558	t	-2524	c	465	t
144	-2341	c	116	t	-1622	c	151	t
160	275	t	264	t	300	t	435	t

b) Stress Ratios

	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative				Stage 4			
LENGTH	DL+PS+APS				DL+PS+ADL+APS			
(ft)	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	4.05	t	3.80	t	4.44	t	6.23	t
16	0.47	c	1.67	t	0.33	c	2.14	t
32	0.62	c	7.98	t	0.51	c	6.64	t
48	0.20	c	0.43	c	0.28	c	0.41	c
64	0.27	c	0.37	c	0.49	c	0.32	c
80	0.18	c	0.30	c	0.35	c	0.23	c
96	0.27	c	0.37	c	0.49	c	0.32	c
112	0.20	c	0.43	c	0.28	c	0.41	c
128	0.62	c	7.94	t	0.51	c	6.60	t
144	0.47	c	1.66	t	0.33	c	2.15	t
160	3.91	t	3.75	t	4.26	t	6.19	t

$f'_{c\,@\,28\,days} = 4500$ psi

$f'_c = 1.10 \times f'_{c\,@\,28\,days}$

$f'_c = 4950$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

Table 4.4c: Summary Results for Bridge 1873 Span 3

a) Stress Values

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1 (psi)				Stage 2 (psi)				Stage 3 (psi)			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	-582	c	485	t	330	t	466	t	341	t	666	t
6	-616	c	168	c	-998	c	251	c	-732	c	264	t
12	-614	c	127	c	-870	c	224	c	-639	c	224	t
18	-616	c	124	c	-704	c	244	c	-440	c	275	t
24	-630	c	128	c	-587	c	281	c	-389	c	320	t
30	-663	c	146	c	-704	c	312	c	-600	c	348	t
36	-702	c	-1025	c	-1170	c	-1224	c	-1177	c	-1223	c
42	-764	c	-1104	c	-1792	c	-1189	c	-1869	c	-1155	c
48	-809	c	-978	c	-2211	c	-925	c	-2305	c	-882	c
54	-795	c	-832	c	-2075	c	-649	c	-2134	c	-619	c
60	51	c	-468	c	196	t	91	c	198	t	85	t

b) Stress Ratios

LENGTH (ft)	COMPLETE 100% REMOVAL OF THE DECK											
	Stage 1				Stage 2				Stage 3			
	DL+PS				DL+PS				DL+PS+ADL			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	0.12	c	6.90	t	4.70	t	6.62	t	4.85	t	9.46	t
6	0.12	c	2.39	t	0.20	c	3.56	t	0.15	c	3.75	t
12	0.12	c	1.81	t	0.18	c	3.19	t	0.13	c	3.18	t
18	0.12	c	1.77	t	0.14	c	3.46	t	0.09	c	3.90	t
24	0.13	c	1.82	t	0.12	c	4.00	t	0.08	c	4.54	t
30	0.13	c	2.08	t	0.14	c	4.43	t	0.12	c	4.94	t
36	0.14	c	0.21	c	0.24	c	0.25	c	0.24	c	0.25	c
42	0.15	c	0.22	c	0.36	c	0.24	c	0.38	c	0.23	c
48	0.16	c	0.20	c	0.45	c	0.19	c	0.47	c	0.18	c
54	0.16	c	0.17	c	0.42	c	0.13	c	0.43	c	0.13	c
60	0.72	t	0.09	c	2.78	t	1.29	t	2.81	t	1.21	t

a) Stress Values

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative (psi)				Stage 4 (psi)			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	275	t	264	t	300	t	435	t
6	-1755	c	119	t	-1544	c	134	t
12	-1915	c	436	t	-1701	c	334	t
18	-991	c	410	t	-726	c	427	t
24	-622	c	492	t	-418	c	515	t
30	239	t	521	t	327	t	545	t
36	274	t	-1981	c	274	t	-1958	c
42	40	t	-2515	c	-1261	c	-2480	c
48	-1815	c	-3039	c	-1906	c	-2979	c
54	-2841	c	828	t	-2892	c	868	t
60	190	t	171	t	190	t	167	t

b) Stress Ratios

LENGTH (ft)	FULL 100% REPLACEMENT OF THE DECK							
	Stage 3 Alternative				Stage 4			
	DL+PS+APS				DL+PS+ADL+APS			
	TOP FIBER		BOTTOM FIBER		TOP FIBER		BOTTOM FIBER	
0	3.91	t	3.75	t	4.26	t	6.19	t
6	0.35	c	1.70	t	0.31	c	1.90	t
12	0.39	c	6.20	t	0.34	c	4.74	t
18	0.20	c	5.82	t	0.15	c	6.07	t
24	0.13	c	6.99	t	0.08	c	7.32	t
30	3.40	t	7.41	t	4.65	t	7.74	t
36	3.89	t	0.40	c	3.89	t	0.40	c
42	0.57	t	0.51	c	0.25	c	0.50	c
48	0.37	c	0.61	c	0.39	c	0.60	c
54	0.57	c	11.77	t	0.58	c	12.33	t
60	2.70	t	2.43	t	2.70	t	2.37	t

$f'_{c\ @\ 28\ days} = 4500$ psi

$f'_c = 1.10 \times f'_{c\ @\ 28\ days}$

$f'_c = 4950$ psi

Compression

$\phi = f_c / f'_c$

Tension

$\phi = f_c / \sqrt{f'_c}$

Chapter 5

Summary and Conclusions

5.1 Summary

The purpose of this research was to investigate the removal and replacement of post-tensioned, box-girder bridge decks. A survey of nine western state DOTs was conducted. A list of possible bridges was compiled from which four specific bridges were selected for analyses. The four bridges selected were two simple span bridges (skewed and non-skewed), a 2-span continuous bridge, and a 3-span continuous bridge. A 2D analysis was conducted on all four bridges, and compared to a more complex 3D finite element analysis. The stresses were then checked against allowable stresses.

In the case of the simple span bridges, stresses were exceeded when the deck was directly removed and replaced. Stresses were also exceeded when the deck was taken off and replaced in stages. A method to reduce the stresses was to add external post-tensioning to the bottom sofit of each simple span bridge. An equation was produced to measure the amount of additional prestressing added to the bottom sofit. This equation had to be modified for prestress losses and anchorage losses. It was also shown that the amount of skew did not make a difference in determining the amount of additional prestress needed.

For the continuous span bridges, different results were found. The two-span and three span bridge exceeded maximum stress values even when additional prestressing was added. This bridge will require shoring if the deck must be removed and replaced.

Finally, design considerations and a traffic analysis were conducted for the removal and replacement of the bridge decks.

5.2 Conclusions

In conclusion, deck removal and replacement in cast-in-place, post-tensioned, box-girder bridge decks must be done on a case-by-case basis. If the bridge is simple-span, then additional prestressing can be used to account for the weight of the "wet concrete" decking, outlined in Chapter 3. It is possible to used Eq. 3.2 to find the amount of additional prestressing needed to keep the stresses below the modified AASHTO values of $0.7f'_c$ for extreme compressive fibers and $6\sqrt{f'_c}$ for extreme tensile fibers. Finally, the anchor has to be designed for the amount of additional prestressing needed, also outlined in Chapter 3.

If the bridge is a continuous-span bridge, then it will have to be evaluated on a case-by-case design basis. A 2D study will have to be performed on the specific bridge, to evaluate if the final construction stresses are under the code values specified by AASHTO, which is outlined in Chapter 4. Also, depending on the bridge, a 3D analysis might have to be performed to evaluate localized stresses due to the removal and replacement of the decks on continuous span bridges, but this is normally not needed.

References

1. ACI 318. 1999. *Building Code Requirements for Reinforced Concrete* (ACI 318-99) *And commentary*-ACI 318R-99. Detroit: American Concrete Institute.

2. AASHTO. 1998. *AASHTO LRFD Bridge Design Specifications*. 2nd ed. Washington, D.C., American Association of State Highway and Transportation Officials.

3. Nawy, Edward G., 1996. *Prestressed Concrete: A Fundamental Approach*. Upper Saddle River, New Jersey.

Appendix A

Survey of Western State DOTs

MEMORANDUM

University of Nevada Reno
Reno, Nevada 89557

To Whom It May Concern:

Our engineering department is conducting research on Cast-in-Place, Post-Tensioned, Box-Girder Bridge decks. We are attempting to remove and replace bridge decks in these certain types of bridges. One of the problems with the decks is that they have a short life span, with salting, expansion and contracting of weather, and various other elements. To find a more economically feasible way to repair the decks than to replace the bridge would be a huge benefit.

When the decks of the bridges are removed, the prestress no long helps the bridge, but it hurts the bridge. Our main concern is that the critical stresses might exceed code specifications, and possibly even cause failure in the bridge system.

Our department is trying to find out if any prior research or experimentation has been done on this topic to help us further with our research.

We are coming very close to a solution with simple span bridges, but we are having many problems with any continuous span bridge.

Please fill out the attached survey and return it back to our department as soon as possible. Thank you for your time.

Sincerely

Frank Anthony Reppi
UNR Graduate Student

Deck Removal of Post-Tensioned, Cast-In-Place,
Box Girder Bridges

Department Of Transportation Survey

Conducted by the Civil Engineering Department

University of Nevada, Reno.

Department of Civil Engineering/ Mailstop #258
University of Nevada, Reno Nevada 89557

The University of Nevada, Reno is conducting research on the deck removal of post-tensioned, cast-in-place, box girder bridges. The purpose of this survey is to find out if any prior work or research has been done in the removal of these specific kinds of decks. Post-tensioned, cast-in-place, box girder bridges are very popular in Nevada. Since the deck is added before prestressing, it becomes an integral part of the bridge system (i.e. in resisting prestressing). Therefore, if the top deck is removed critical stresses may exceed desired levels. We greatly appreciate your input into the survey. If you have any questions or comments please feel free to contact us at any of the numbers given. Please complete and return the survey by July 25, 1999. Thank You.

State________________________Name____
LAST FIRST

MailingAddress____
ADDRESS

____
CITY STATE ZIP CODE

Phone Number (_____)______________________

Has your DOT ever removed (fully or partially) a cast in place, post-tensioned, box girder bridge deck? **YES** **NO**

If yes, please answer the following questions.
If there are multiple bridges, please copy and complete this section for each bridge.

Please specify the bridge number and the bridge location.

Was the bridge simple span or continuous span?

When was the deck removed?

How many spans were used and what was the length of each span (feet)?
Note: Only use one span and the respective length for simple span bridges.

What was the width of the bridge (feet)?
What is the amount of bridge skew (degrees)?

What was the initial jacking force used in the tendons (kips)?

For the effective long-term prestress level, what were the total losses and how were the losses assumed (kips or ksi)?

Please specify the strength of the concrete used, the cross-sectional area of the bridge, and the moment of inertia (psi, ft^2, ft^4).

How was the deck removed (i.e. fully, partially, staged)?

Were there any areas where the stresses became critical? If so where?

NOTE: If it is easier then please feel free to provide use with plans and calculations.

This survey is being conducted by Frank Reppi,
under the supervision of Dr. David Sanders and Dr. Ahmad Itani.

Contacts
Frank Reppi (F_Reppi@hotmail.com)
Dr. David Sanders (775-784-4288 or sanders@unr.edu)

Please complete and return this survey by February 20 2001 .

Appendix B

Sample Calculations

Bridge G1697S
Bridge I1301E

Calculations for Bridge G1697S

Designing the additional Jacking Force needed on the System

Bridge Section Properties:

	Full deck	No deck
I_{xx} *(ft^4)*	373.9	119
A_c *(ft^2)*	84.85	48.42
Y_{top} *(ft)*	2.34	3.84
Y_{bott} *(ft)*	3.16	1.66
e_{br} *(ft)*	2.37	0.87

Bridge Design Properties:
Span Length (L) = 132 ft
Total Effective Prestress (P_{eff}) = 10,788 kips
Moment Dead Load of Full Deck (M_{full}) = 27,880 kip-ft
Eccentricity of Additional Anchor with full deck $(e_{add})_{\textbf{full deck}}$ = 3.16 + 2 = 5.16 ft
Eccentricity of Additional Anchor without deck $(e_{add})_{\textbf{no deck}}$ = 1.66 + 2 = 3.66 ft

28-day Concrete Strength (f'_c) = 4550 psi
Concrete Strength used ($f'_{c\ used}$) = 1.1 × 4550 = 5005 psi

Therefore, by Using Equation 3-2
Amount of additional effective prestress needed not including losses (P_{add}) = **4,081.5 kips**

Abutment losses (α) = 2 × 9/132 = 0.136 = 13.6% (using Equation Eq3-3)
Prestress losses = 5%

Final Additional Prestressing Value
Amount of additional jacking prestress needed (P_{aj}) = (4,081.5)(1.05)(1.136) = **4,870 kips**

Designing the Interior Anchor Blocks
Total number of girders = 2 exterior + 4 interior = 6 total girders
Total Number of Interior Anchor Blocks = (4 interior girders) × 2 + (2 exterior girders) × 1 = 10 blocks
Jacking Force per anchor block = 4,870 kips / 10 = 487 kips

(Since shear force is being controlled and regulated, use a load factor of 1.2)
Ultimate shear force per anchor block (V_u) = 1.2 × 487 = 585 kips

Design of Shear Steel in Anchor Block (Reference Figure 3.6 for all Steel)
(Assume all shear goes into shear steel; and transferred into the web use shear friction method)

Friction Coefficient (μ) = 1.0 (All contact surfaces must me roughened to ¼ inch minimum amplitude; AASHTO 5.8.4.2)

Shear friction $\phi = 0.85$
$f_y = 60$ ksi

$\phi V_n = \phi A_{vf} f_y \mu = V_u$ (AASHTO 5.8.4.1-1)

Therefore, $A_{vf} = 11.5\ in^2$

Use #6 bar grouted in the girders. $d_b = 0.75$ in; $A_s = 0.44\ in^2$
Number of Bars Used in Shear = 11.5 in^2 / 0.44 in^2 = **26 Bars**.

Development of Shear Steel in Tension (AASHTO 5.11.2)
$f_y = 60$ ksi
$f'_c = 4$ ksi
Concrete Cover = 2 in

Transverse Steel
$f_{yt} = 60$ ksi
Use a #6 bar for design in anchor block. $d_b = 0.75$ in; $A_s = 0.44\ in^2$
Use 4 - #4 bars at 5 inch spacing for transverse steel in anchor block.

$$\ell_{db} = \frac{1.25 A_b f_y}{\sqrt{f'_c}}$$

$$\ell_{db} = \frac{1.25(0.44)(60)}{\sqrt{4.0}}$$

Then $\ell_{db} = 16.5$ in

$$\ell_{db\,min} = 0.4 d_b f_y$$

$$\ell_{db\,min} = 0.4(0.75)(60)$$

Then $\ell_{db\,min} = 18.0$ in

Finally, the total width of each anchor block from the face of the girder = 18.0 in + 2 in cover = 20; use 24 in or **2 ft width with 2 inches of cover and longer #6 bars**.

Design Number of Tendons, Anchorage Size, and Block Dimensions
For tendons, use 0.6 in, seven-wire strand, grade 270. $A_s = 0.217\ in^2$

Jacking strength of tendons = (0.70)(270 ksi)(0.217 in^2) = 41 kips per tendon.

Therefore, number of tendons per anchor = 585 kips / 41 kips per tendon = **15 tendons per anchor.**

Anchorage Size 15-0.60" anchor
Maximum diameter = 12.5 inches
Length = 22.63 inches
Use a 2-inch minimum clear distance.
Block Dimensions
Place anchor at a 30-degree angle from horizontal.

$$\text{Block Height} = \left(2 \times 2^{\text{in}}\ \text{clear distance}\right) + \left(22.63^{\text{in}}\ \text{length} \times \sin 30°\right) + \left(12.5^{\text{in}}\ \text{diameter} \times \sin 60°\right)$$

$$\textbf{Block Height} = \textbf{27 inches}$$

$$\text{Block Length} = \left(\frac{27^{\text{in}}\ \text{block height}}{\tan 30°}\right) + \left(\frac{27^{\text{in}}\ \text{block height}}{\tan 60°}\right)$$

$$\textbf{Block Length} = \textbf{63 inches}$$

Block Width = 24 inches

<u>Check Bearing on Bottom Sofit of Bridge (AASHTO 5.7.5)</u>

$$A_1 = \text{loaded area} = (63^{\text{in}} \times 24^{\text{in}}) = 1512\ \text{in}^2$$

$$A_2 = \text{at bottom plane of soffit} = (63^{\text{in}} + 2 \times 6^{\text{in}}\ \text{soffit})(24^{\text{in}} + 2 \times 6^{\text{in}}\ \text{soffit}) = 2700\ \text{in}^2$$

$$\sqrt{\frac{A_2}{A_1}} = \sqrt{\frac{2700}{1512}} = 1.34\ \text{is} \le 2.0\text{; Therefore is ok.}$$

$$\text{P}_\text{u} \le \phi\text{P}_\text{n} = \phi\left(0.85\text{f'}_\text{c}\ \text{A}_1\right)\left(\sqrt{\frac{A_2}{A_1}}\right) = 0.70\left(0.85 \times 4{,}550^{psi} \times 1512^{in^2}\right)(1.34)$$

$$\phi P_n = 5{,}485\ \text{kips} > 585\ \text{kips; therefore, bearing is more than adequate.}$$

Calculations for Bridge I1301E

Designing the additional Jacking Force needed on the System

Bridge Section Properties:

	Full deck	No deck
I_{xx} *(ft^4)*	892.7	431.2
A_c *(ft^2)*	111.3	83.3
Y_{top} *(ft)*	3.83	5.00
Y_{bott} *(ft)*	4.17	3.00
e_{br} *(ft)*	3.27	2.10

Bridge Design Properties:
Span Length (L) = 180 ft
Total Effective Prestress (P_{eff}) = 12,770 kips
Moment Dead Load of Full Deck (M_{full}) = 67,692 kip-ft
Eccentricity of Additional Anchor with full deck $(e_{add})_{\textbf{full deck}}$ = 4.17 + 2 = 6.17 ft
Eccentricity of Additional Anchor without deck $(e_{add})_{\textbf{no deck}}$ = 3.00 + 2 = 5.00 ft

28-day Concrete Strength (f'_c) = 5275 psi
Concrete Strength used ($f'_{c\ used}$) = 1.1 × 5275 = 5803 psi

Therefore, by Using Equation 3-2
Amount of additional effective prestress needed not including losses (P_{add}) = **1507.3 kips**

Abutment losses (α) = 2 × 9/180 = 0.10 = 10.0% (using Equation Eq3-3)
Prestress losses = 5%

Final Additional Prestressing Value
Amount of additional jacking prestress needed (P_{aj}) = (1507.3)(1.05)(1.10) = **1,741 kips**

Designing the Interior Anchor Blocks
Total number of girders = 2 exterior + 2 interior = 4 total girders
Total Number of Interior Anchor Blocks = (2 interior girders) × 2 + (2 exterior girders) × 1 = 6 blocks
Jacking Force per anchor block = 1741 kips / 6 = 290 kips

(Since shear force is being controlled and regulated, use a load factor of 1.2)
Ultimate shear force per anchor block (V_u) = 1.2 × 290 = 348 kips

Design of Shear Steel in Anchor Block (Reference Figure 3.6 for all Steel)
(Assume all shear goes into shear steel, transferred into the web, and use shear friction method)

Friction Coefficient (μ) = 1.0 (All contact surfaces must me roughened to ¼ inch minimum amplitude; AASHTO 5.8.4.2)

Shear friction $\phi = 0.85$
$f_y = 60$ ksi

$\phi V_n = \phi A_{vf} f_y \mu = V_u$ (AASHTO 5.8.4.1-1)

Therefore, $A_{vf} = 6.82$ in^2

Use #6 bar grouted in the girders. $d_b = 0.75$ in; $A_s = 0.44$ in^2
Number of Bars Used in Shear = 6.82 in^2 / 0.44 in^2 = **16 Bars**.

<u>Development of Shear Steel in Tension (AASHTO 5.11.2)</u>
$f_y = 60$ ksi
$f'_c = 4$ ksi
Concrete Cover = 2 in

Transverse Steel
$f_{yt} = 60$ ksi
Use a #6 bar for design in anchor block. $d_b = 0.75$ in; $A_s = 0.44$ in^2
Use 4 - #4 bars at 5 inch spacing for transverse steel in anchor block.

$$\ell_{db} = \frac{1.25 A_b f_y}{\sqrt{f'_c}}$$

$$\ell_{db} = \frac{1.25(0.44)(60)}{\sqrt{4.0}}$$

Then $\ell_{db} = 16.5$ in

$$\ell_{db\,min} = 0.4 d_b f_y$$

$$\ell_{db\,min} = 0.4(0.75)(60)$$

Then $\ell_{db\,min} = 18.0$ in

Finally, the total width of each anchor block from the face of the girder = 18.0 in + 2 in cover = 20; use 24 in or **2 ft width with 2 inches of cover and longer #6 bars**.

<u>Design Number of Tendons, Anchorage Size, and Block Dimensions</u>
For tendons use 0.6 in, seven-wire strand, grade 270. $A_s = 0.217$ in^2

Jacking strength of tendons = (0.70)(270 ksi)(0.217 in^2) = 41 kips per tendon.

Therefore, number of tendons per anchor = 348 kips / 41 kips per tendon = **9 tendons per anchor.**

Anchorage Size 9-0.60” anchor
Maximum diameter = 9.0 inches
Length = 13.5 inches
Use a 2-inch minimum clear distance.

Block Dimensions
Place anchor at a 30-degree angle from horizontal plane.

$$\text{Block Height} = \left(2 \times 2^{\text{in}} \text{ clear distance}\right) + \left(13.5^{\text{in}} \text{ length} \times \sin 30°\right) + \left(9.0^{\text{in}} \text{ diameter} \times \sin 60°\right)$$
$$\textbf{Block Height} = \textbf{19 inches}$$

$$\text{Block Length} = \left(\frac{19^{\text{in}} \text{ block height}}{\tan 30°}\right) + \left(\frac{19^{\text{in}} \text{ block height}}{\tan 60°}\right)$$
$$\textbf{Block Length} = \textbf{44 inches}$$

Block Width = 20 inches

<u>Check Bearing on Bottom Sofit of Bridge (AASHTO 5.7.5)</u>

$$A_1 = \text{loaded area} = (44^{\text{in}} \times 20^{\text{in}}) = 880 \text{ in}^2$$
$$A_2 = \text{at bottom plane of soffit} = (44^{\text{in}} + 2 \times 6^{\text{in}} \text{ soffit})(20^{\text{in}} + 2 \times 6^{\text{in}} \text{ soffit}) = 1792 \text{ in}^2$$
$$\sqrt{\frac{A_2}{A_1}} = \sqrt{\frac{1792}{880}} = 1.43 \text{ is} \leq 2.0\text{; Therefore is ok.}$$
$$P_u \leq \phi P_n = \phi\left(0.85 f'_c\ A_1\right)\left(\sqrt{\frac{A_2}{A_1}}\right) = 0.70\left(0.85 \times 5275^{\text{psi}} \times 880^{\text{in}^2}\right)(1.43)$$
$$\phi P_n = 3.950 \text{ kips} > 348 \text{ kips; Therefore bearing is more than adequate.}$$

Appendix C

Figures Related to Chapter 3

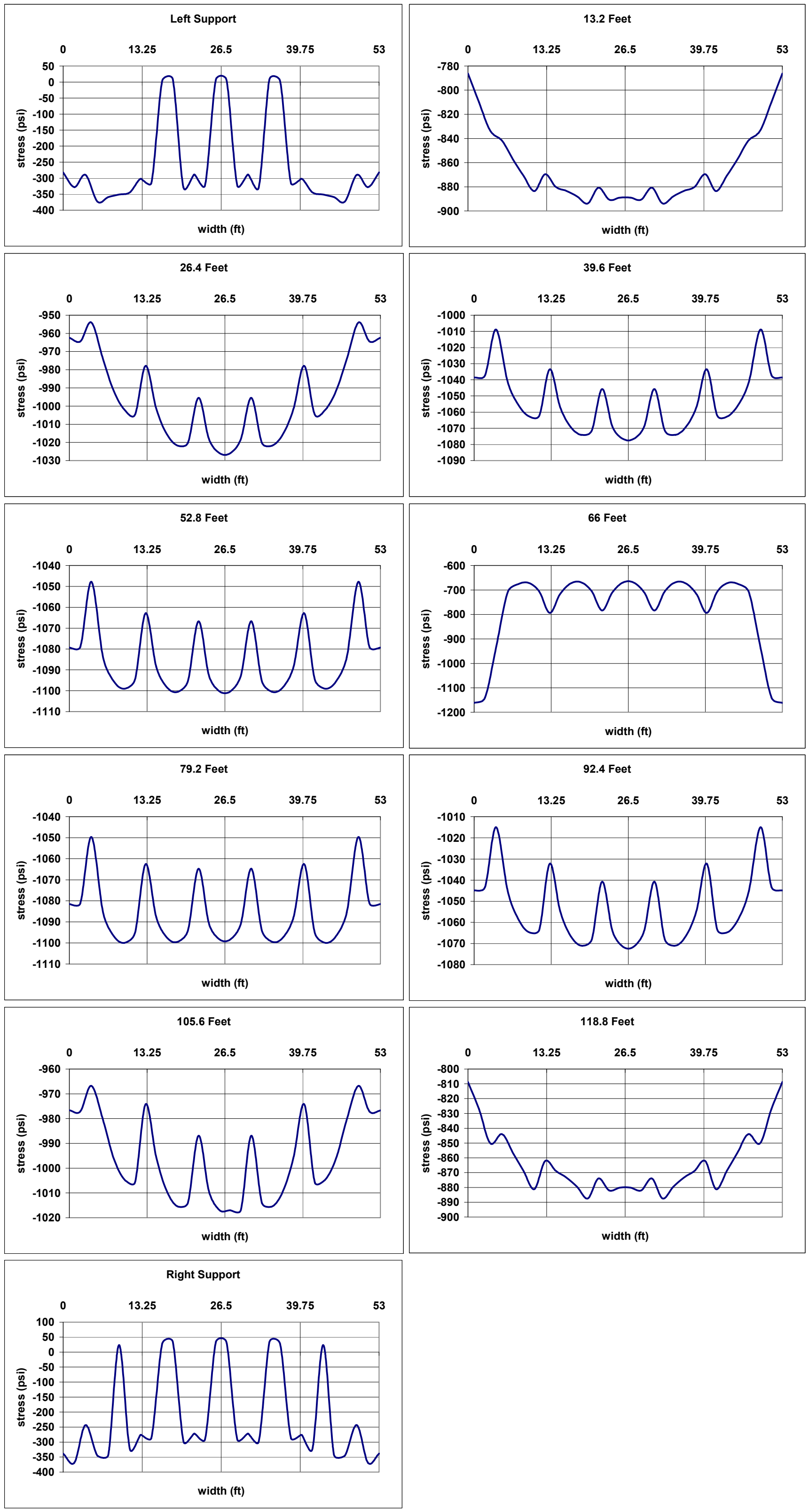

Figure C.1 Bridge G1697S, Full Deck, Top Fiber

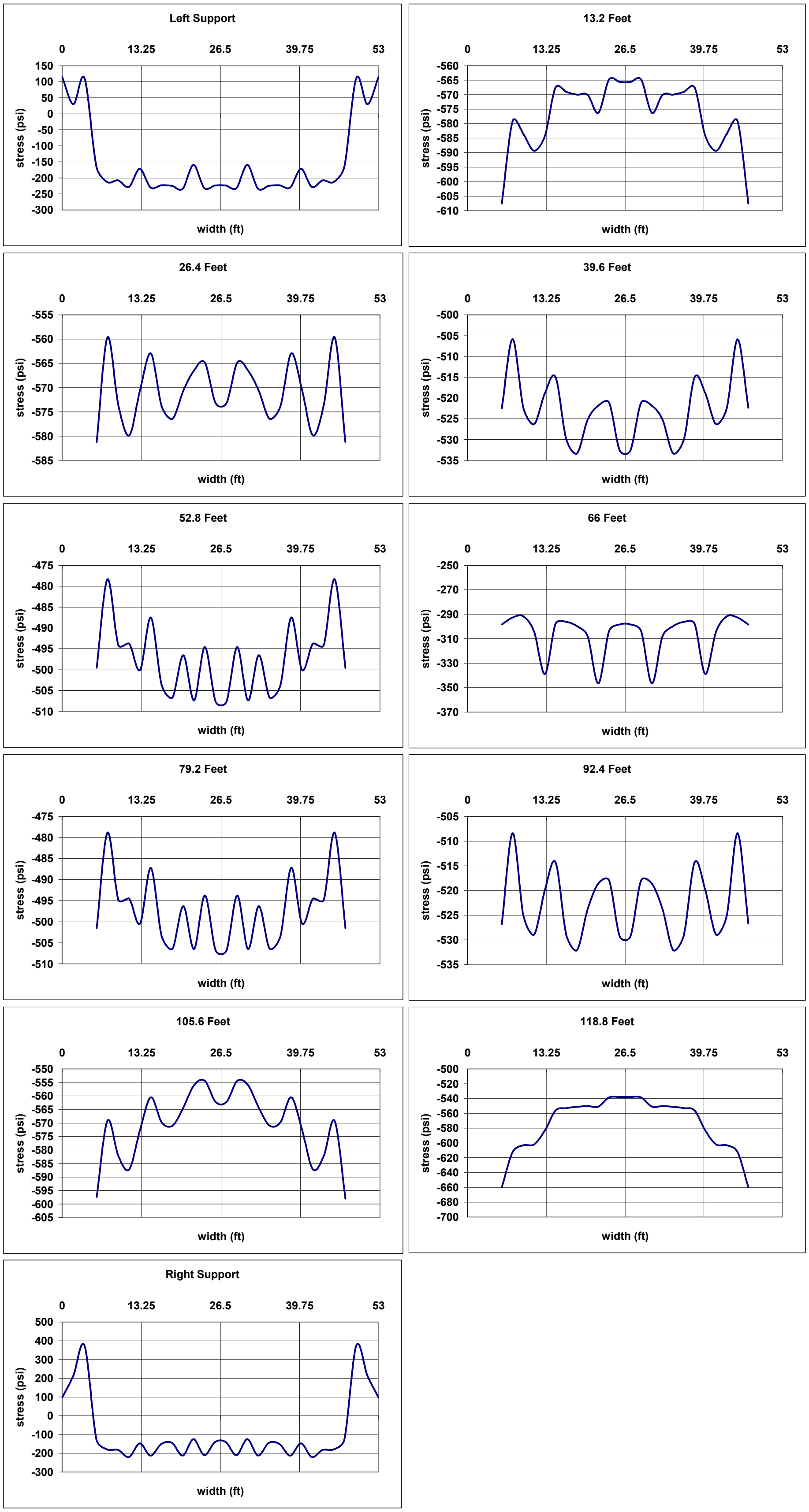

Figure C.2 Bridge G1697S, Full Deck, Bottom Fiber

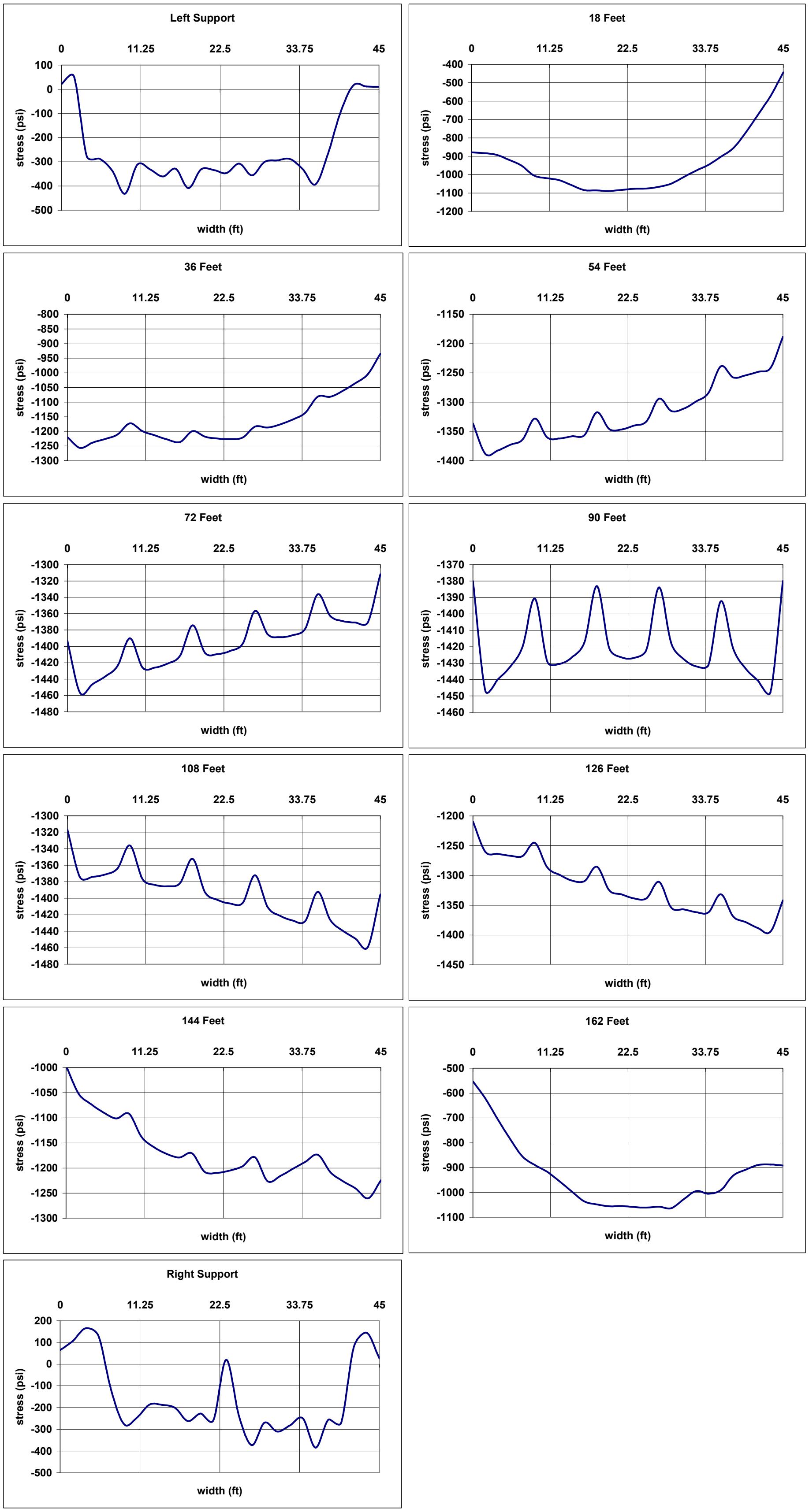

Figure C.3 Bridge I1301E, Full Deck, Top Fiber

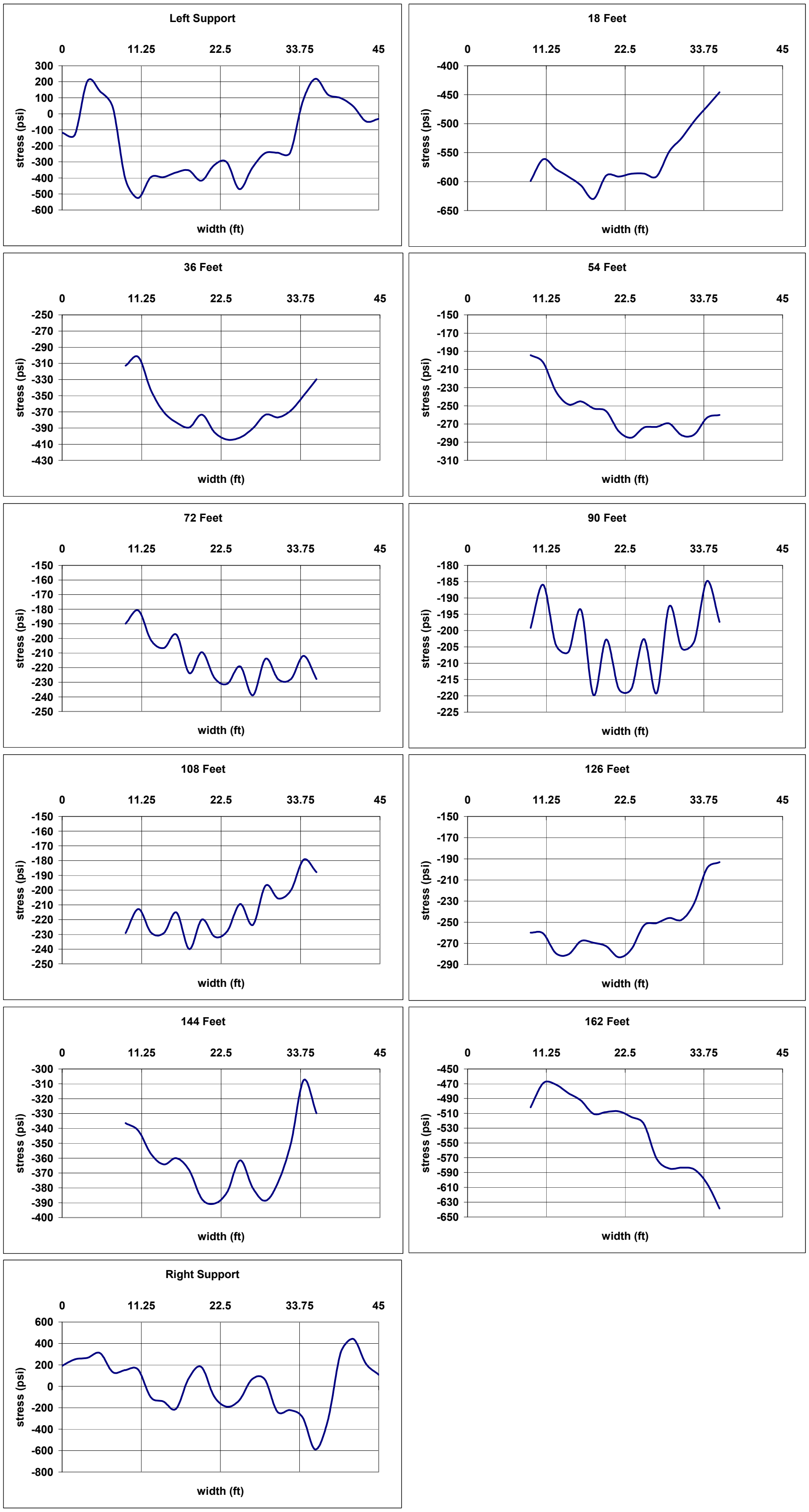

Figure C.4 Bridge I1301E, Full Deck, Bottom Fiber

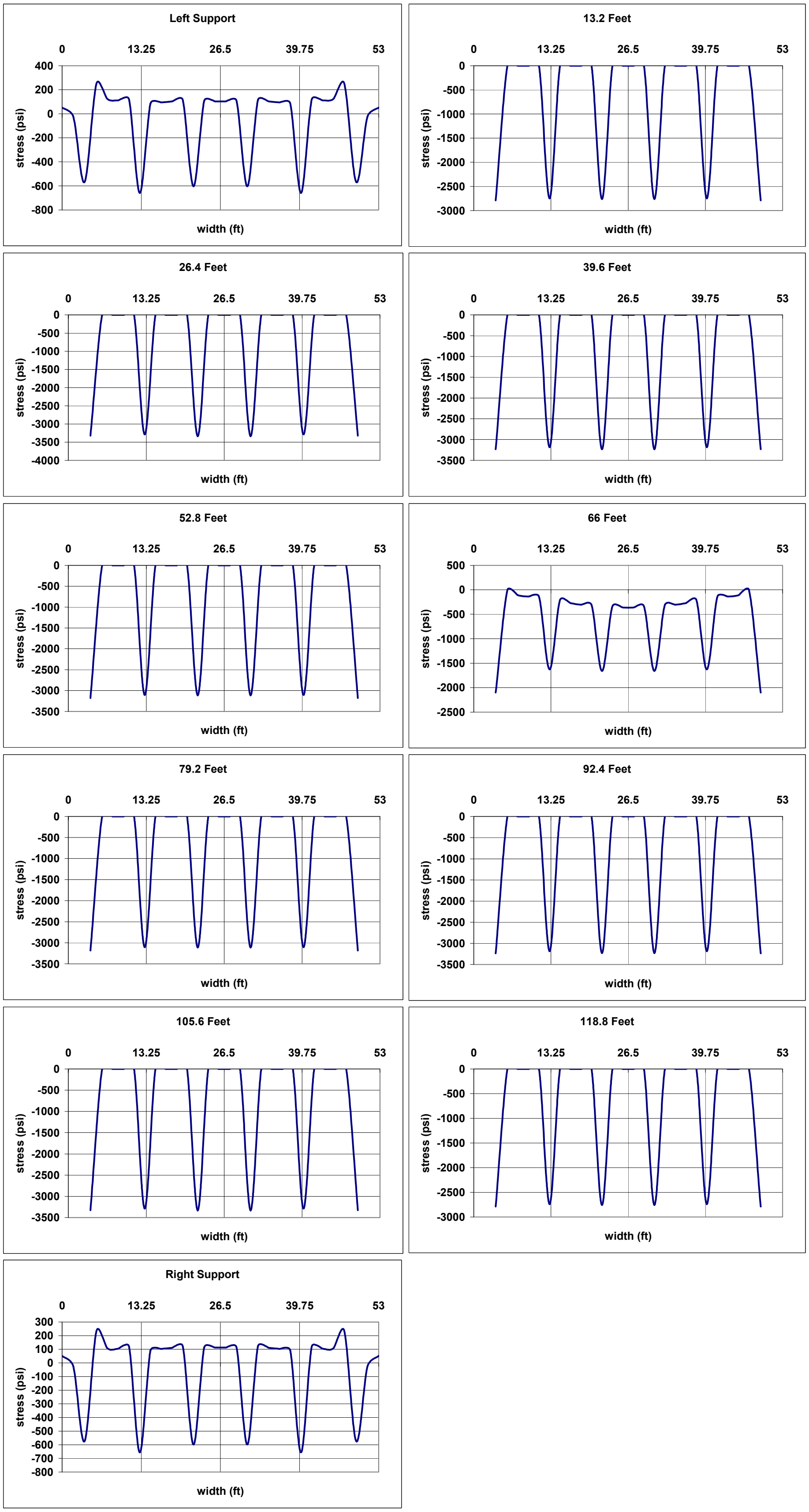

Figure C.5 Bridge G1697S, No Deck, Top Fiber

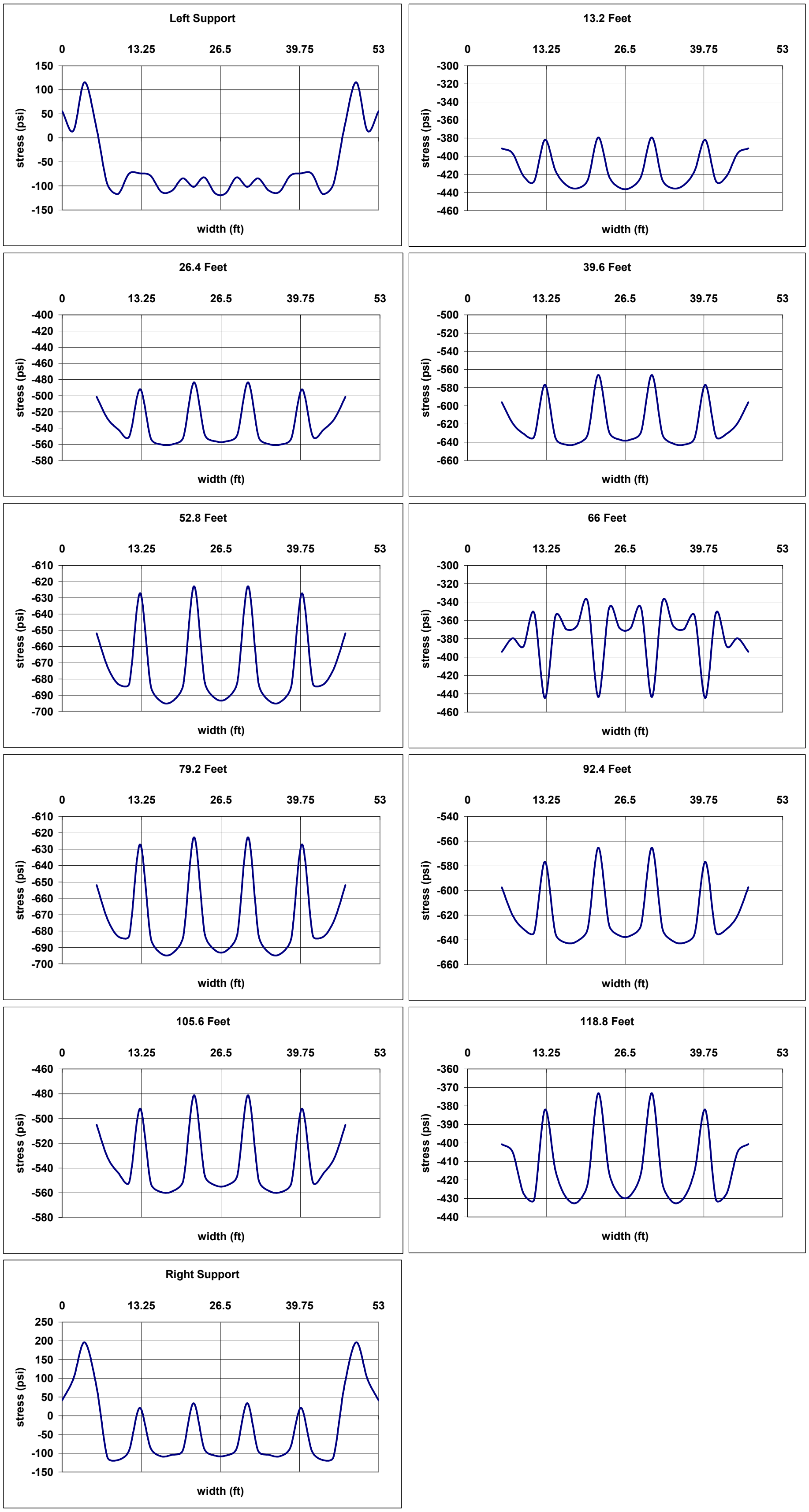

Figure C.6 Bridge G1697S, No Deck, Bottom Fiber

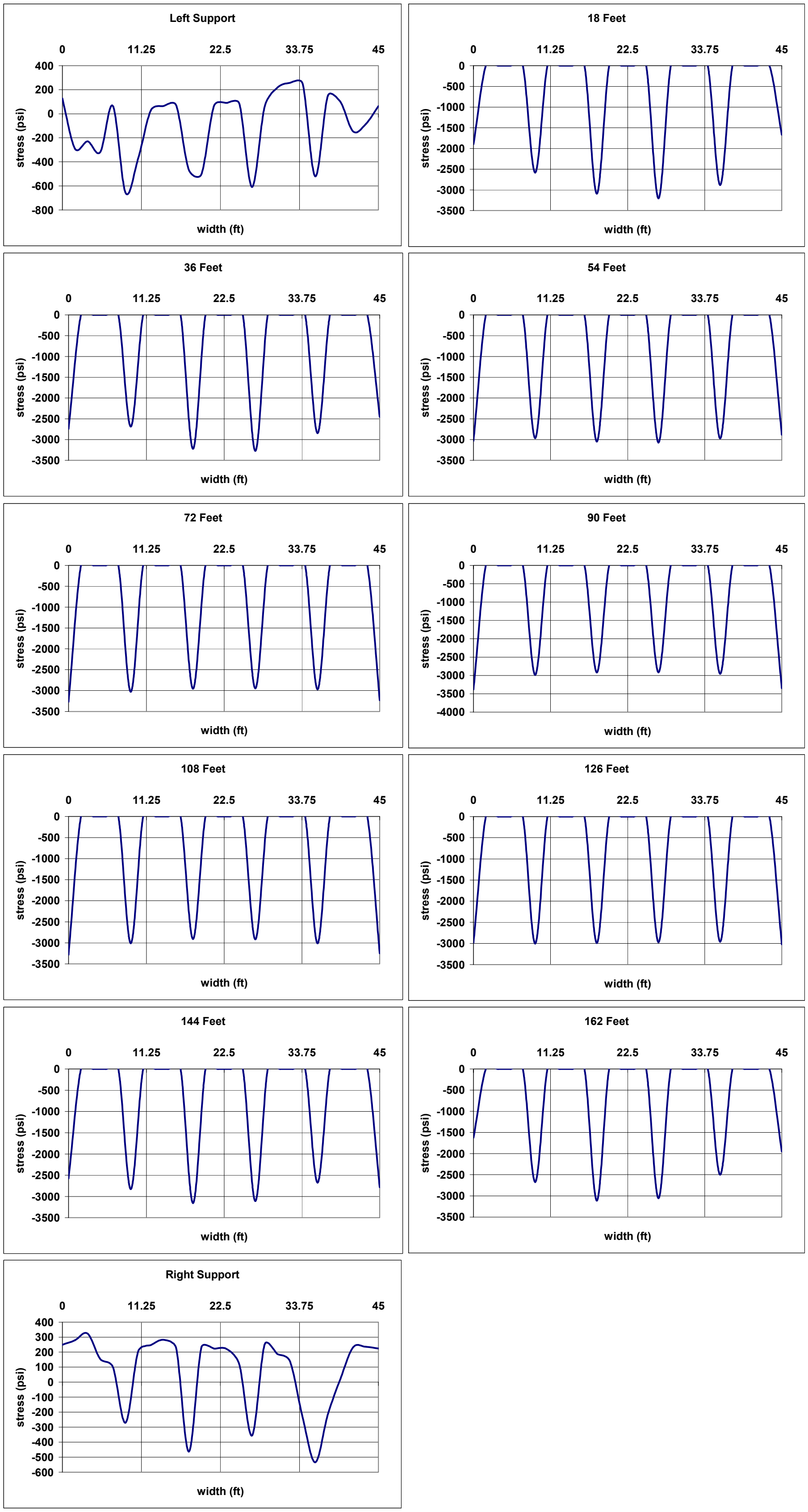

Figure C.7 Bridge I1301E, No Deck, Top Fiber

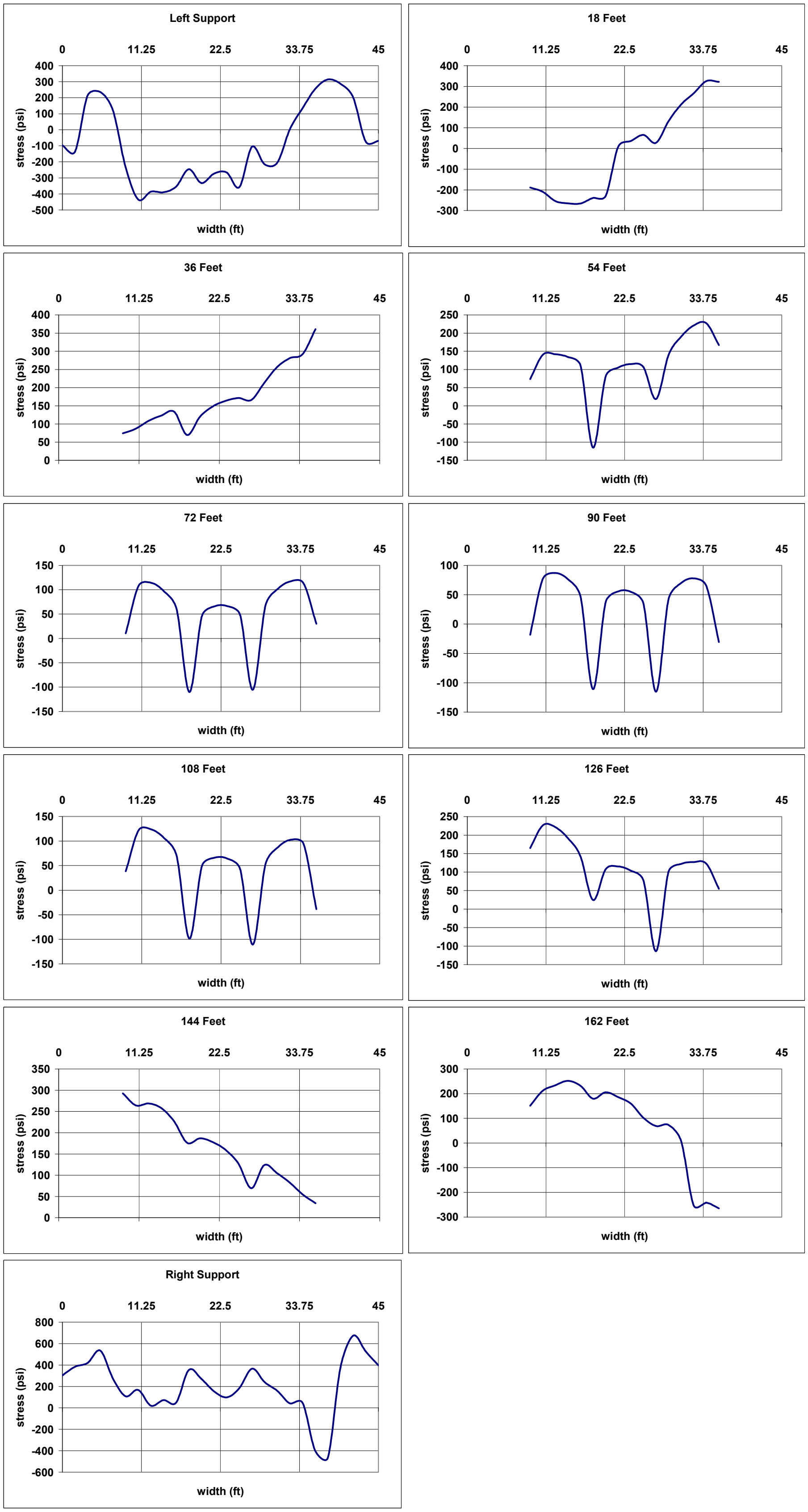

Figure C.8 Bridge I1301E, No Deck, Bottom Fiber

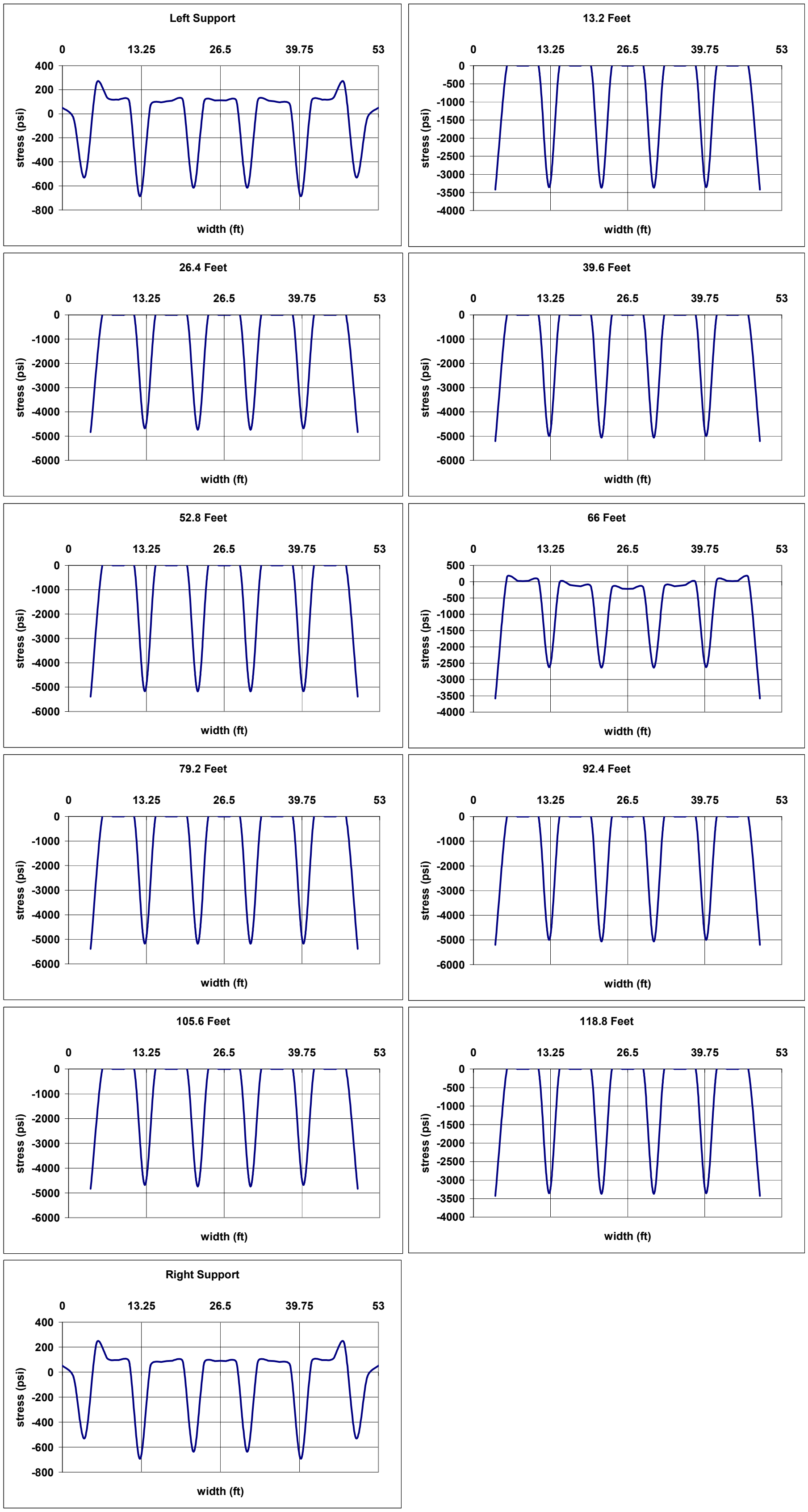

Figure C.9 Bridge G1697S, No Deck, DL+PS+ADL, Top Fiber

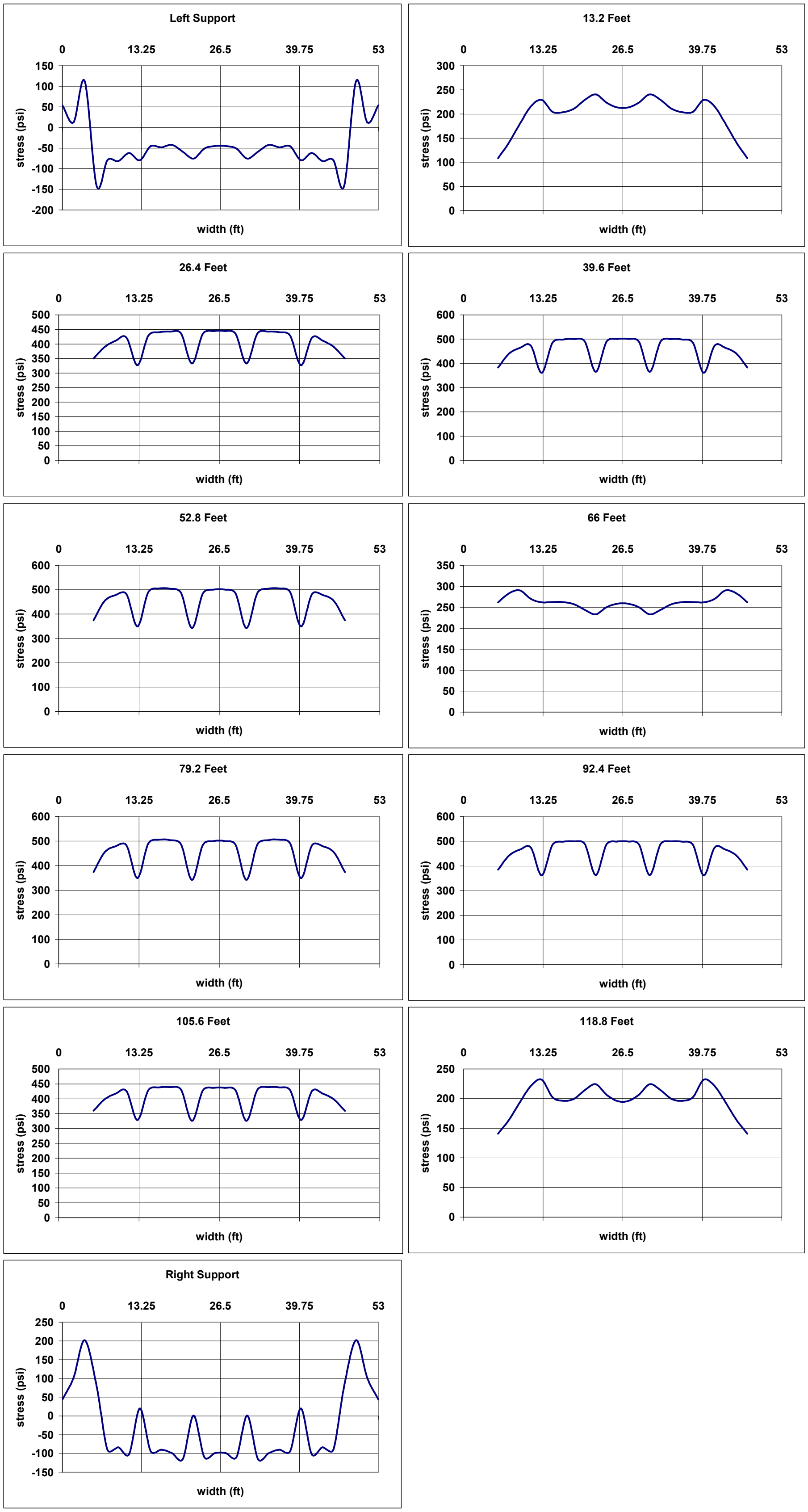

Figure C.10 Bridge G1697S, No Deck, DL+PS+ADL, Bottom Fiber

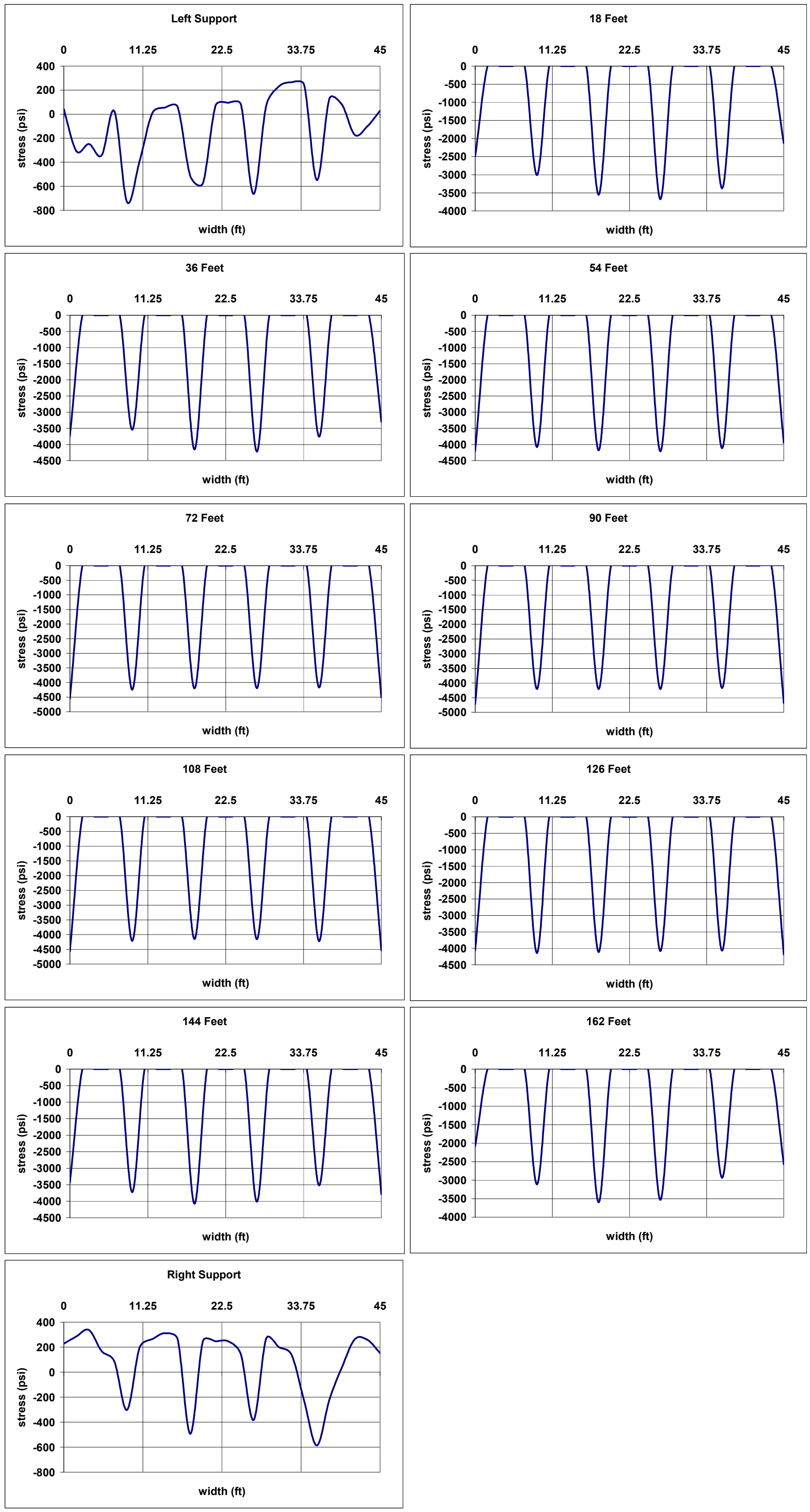

Figure C.11 Bridge I1301E, No Deck, DL+PS+ADL, Top Fiber

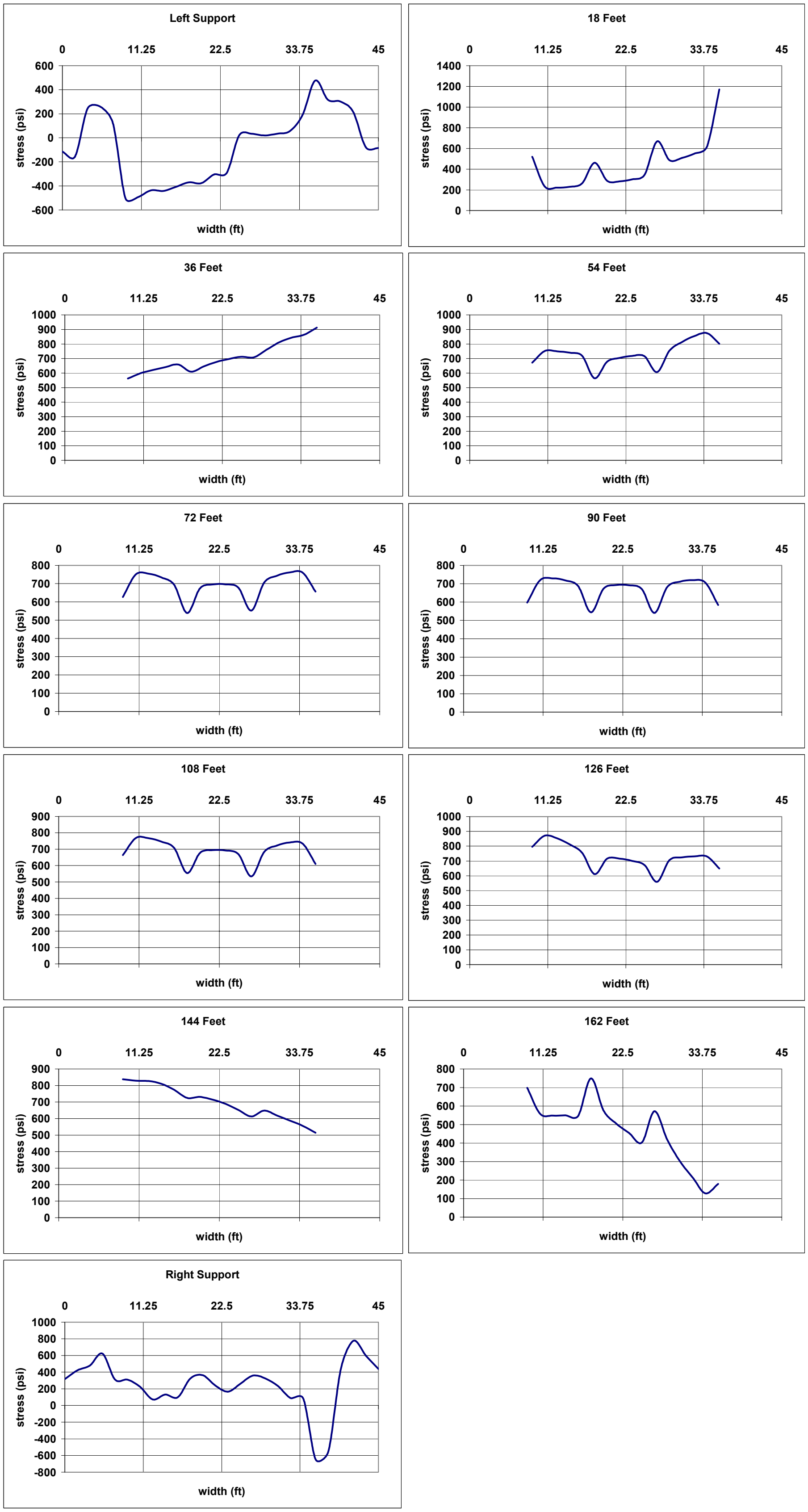

Figure C.12 Bridge I1301E, No Deck, DL+PS+ADL, Bottom Fiber

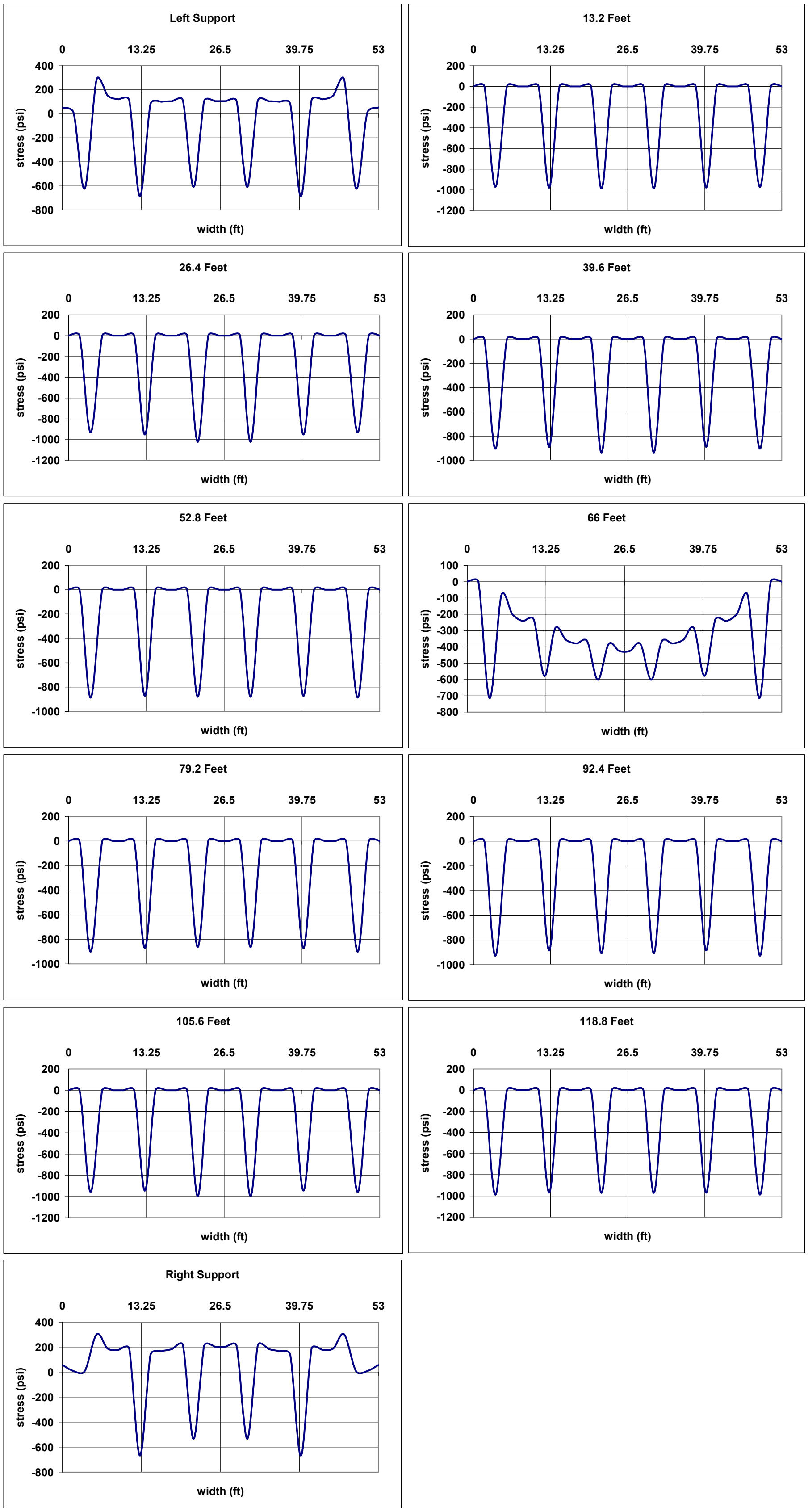

Figure C.13 Bridge G1697S, 100% Deck Removal, Top Fiber

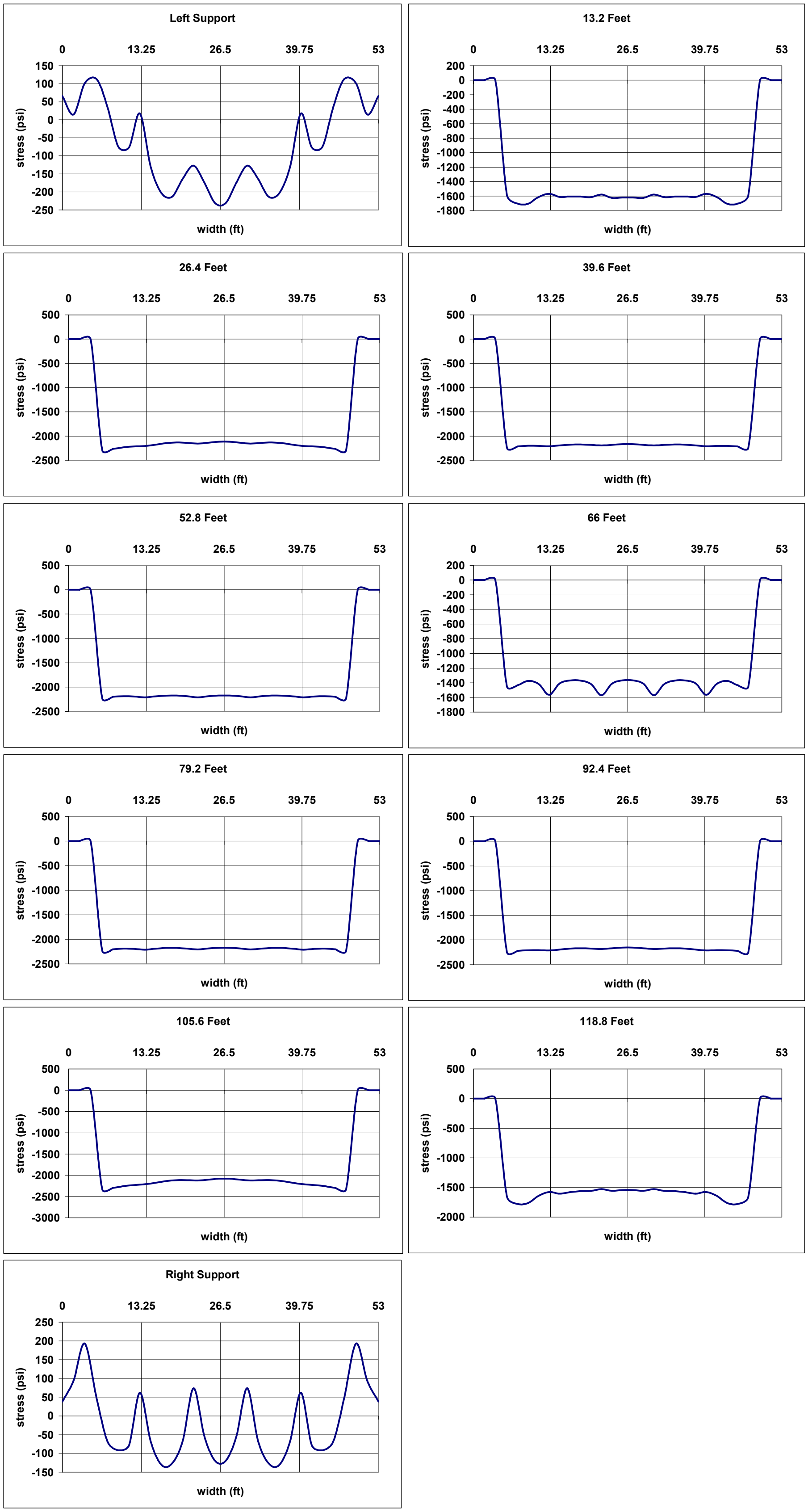

Figure C.14 Bridge G1697S, 100% Deck Removal, Bottom Fiber

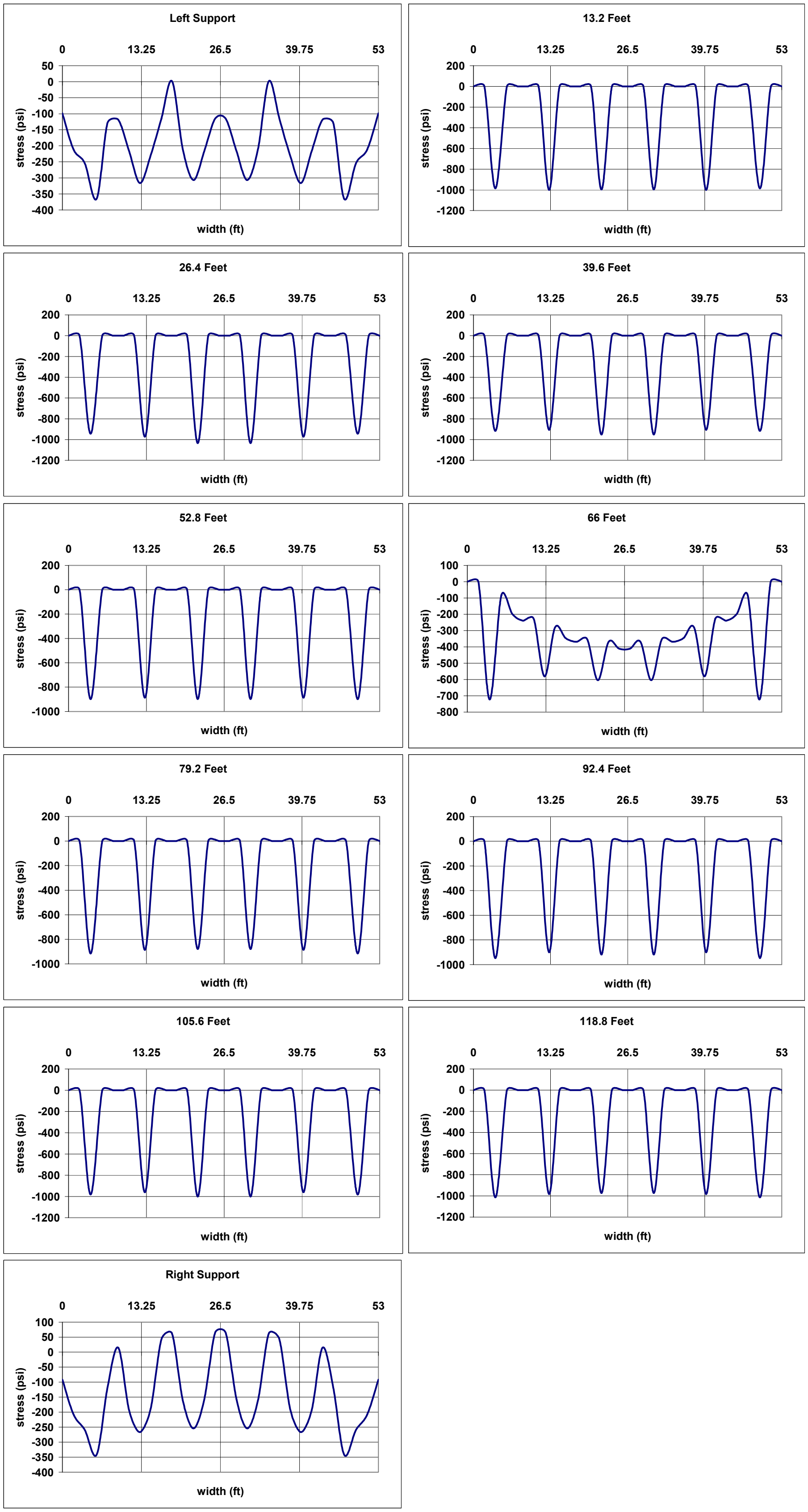

Figure C.15 Bridge G1697S, 90% Deck Removal, Top Fiber

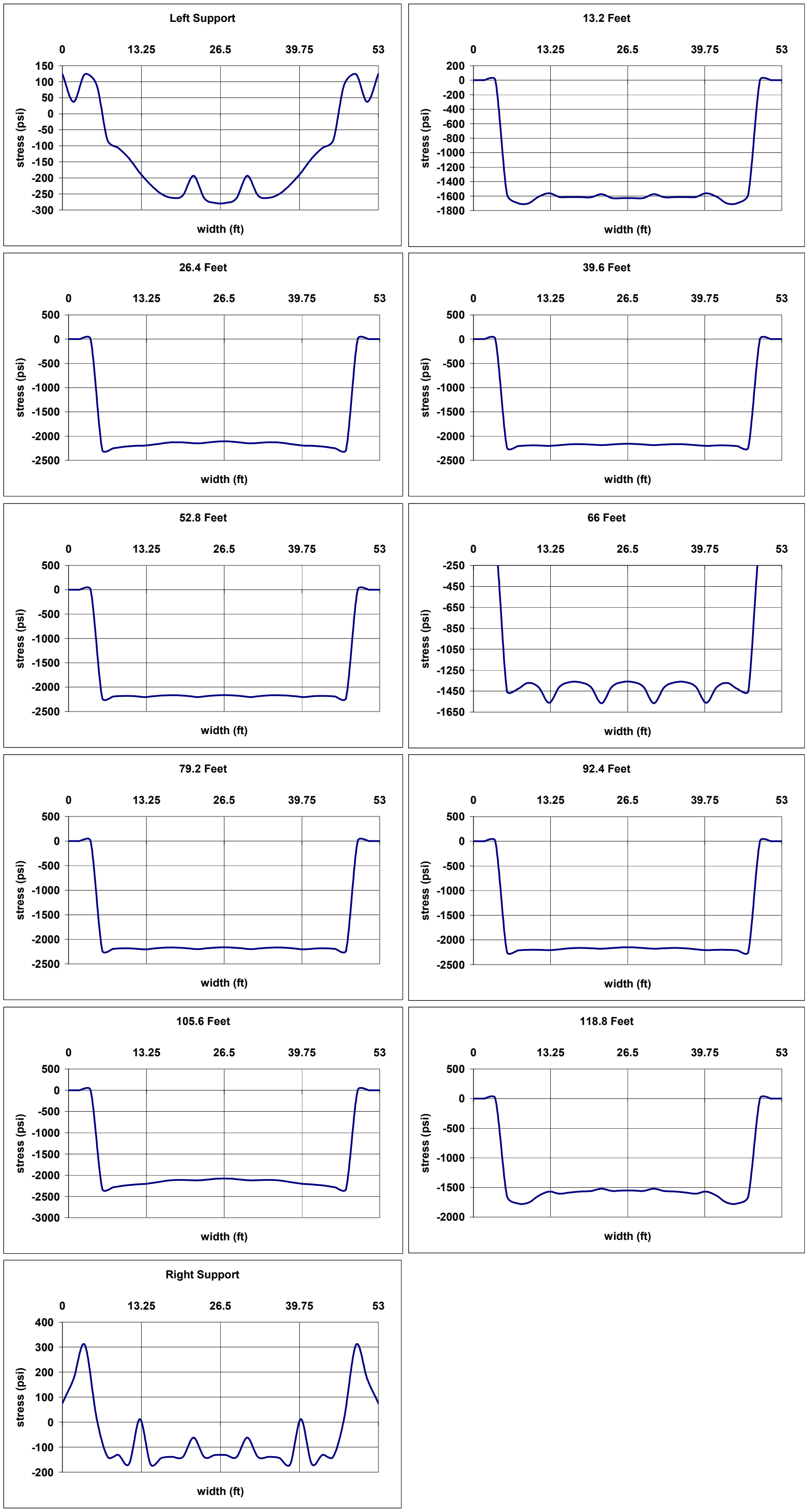

Figure C.16 Bridge G1697S, 90% Deck Removal, Bottom Fiber

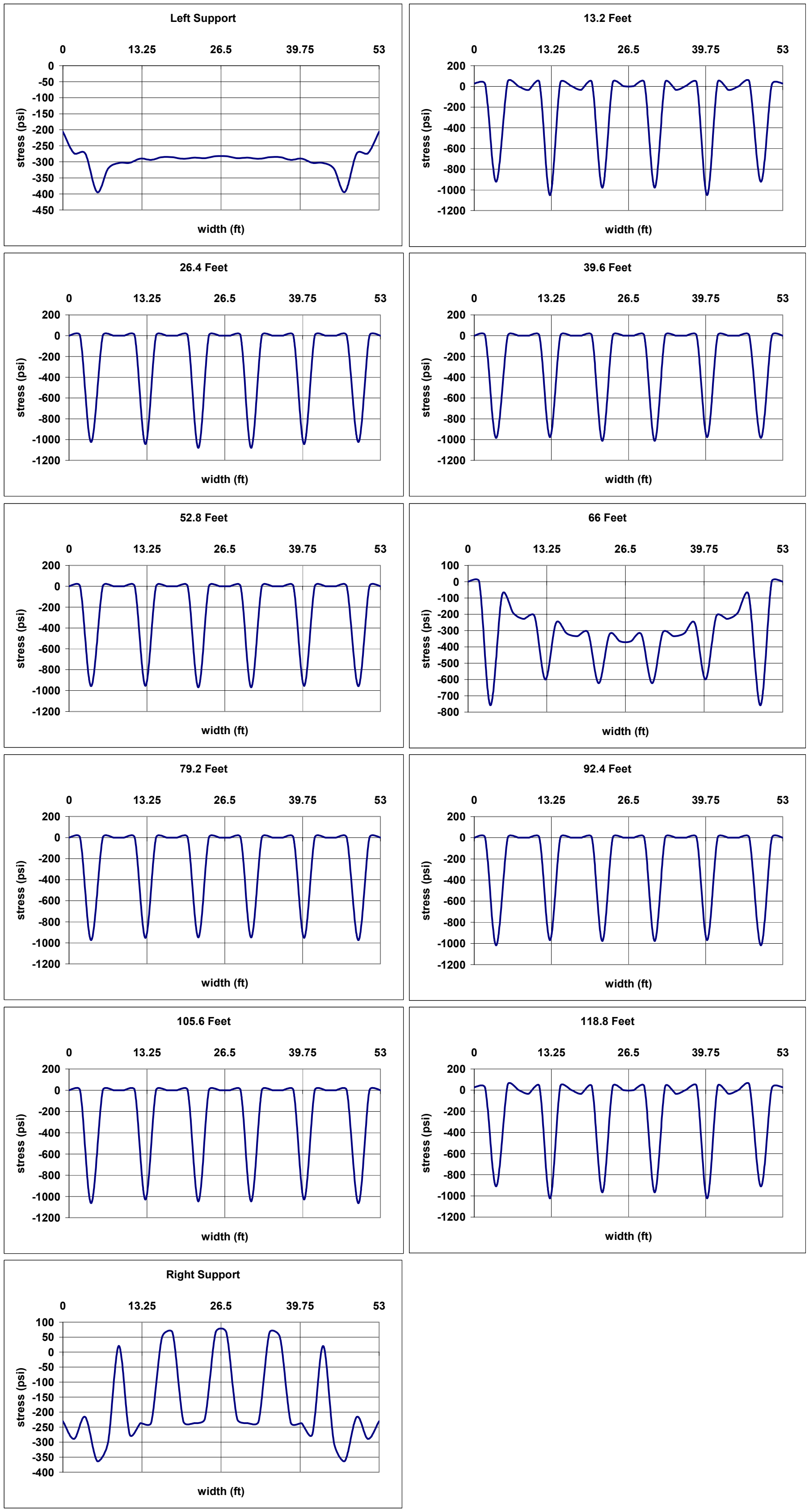

Figure C.17 Bridge G1697S, 80% Deck Removal, Top Fiber

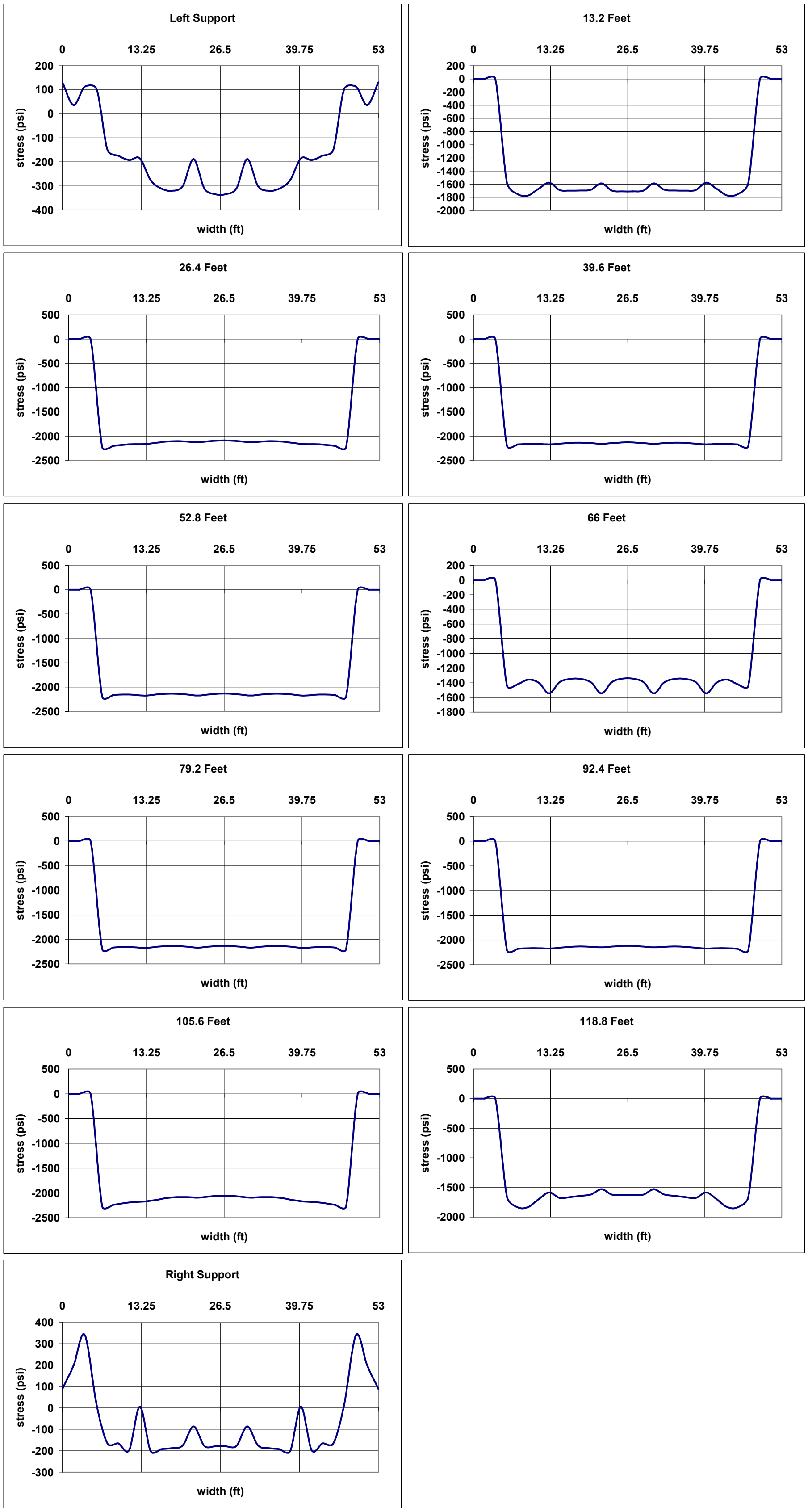

Figure C.18 Bridge G1697S, 80% Deck Removal, Bottom Fiber

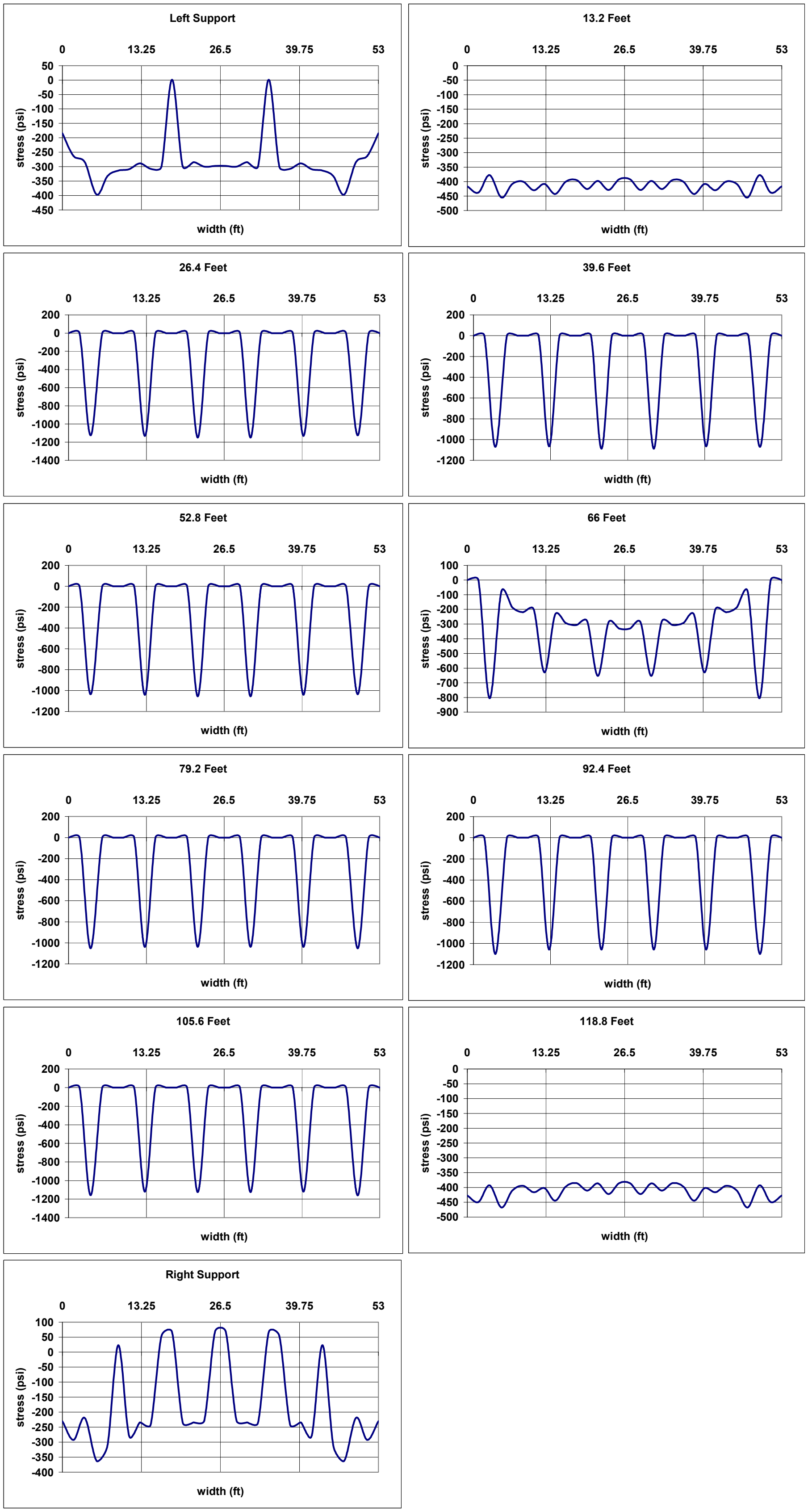

Figure C.19 Bridge G1697S, 70% Deck Removal, Top Fiber

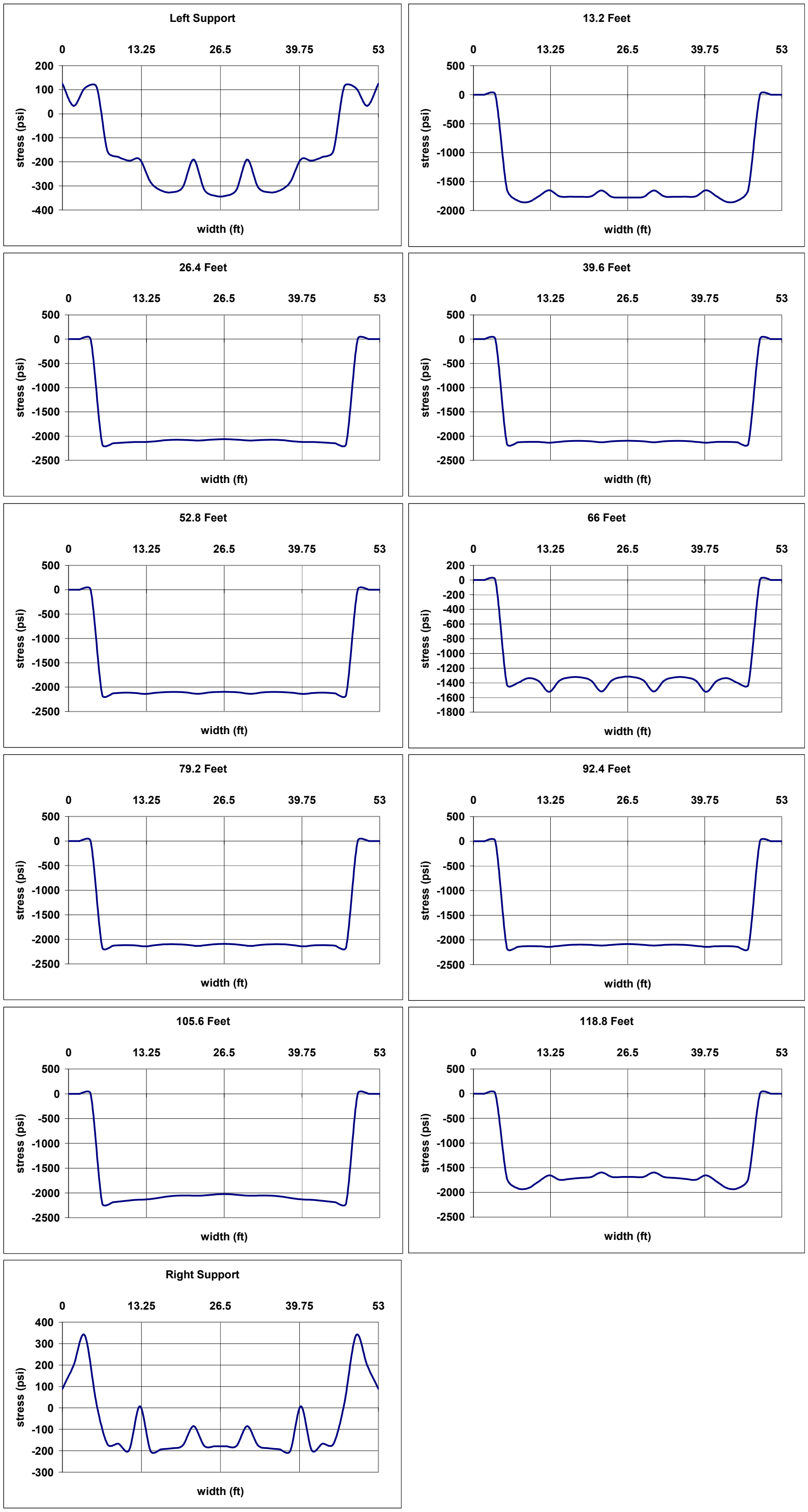

Figure C.20 Bridge G1697S, 70% Deck Removal, Bottom Fiber

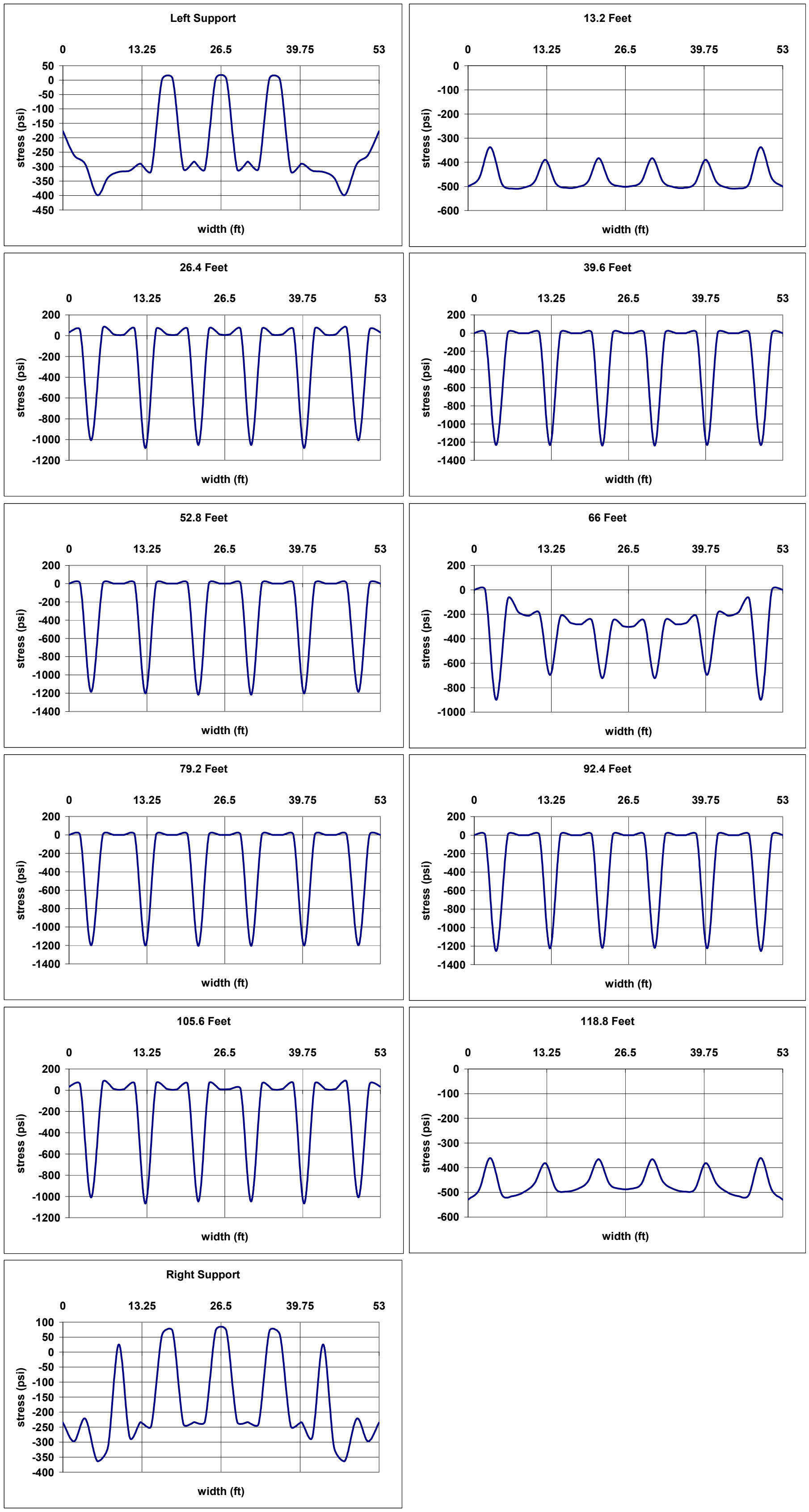

Figure C.21 Bridge G1697S, 60% Deck Removal, Top Fiber

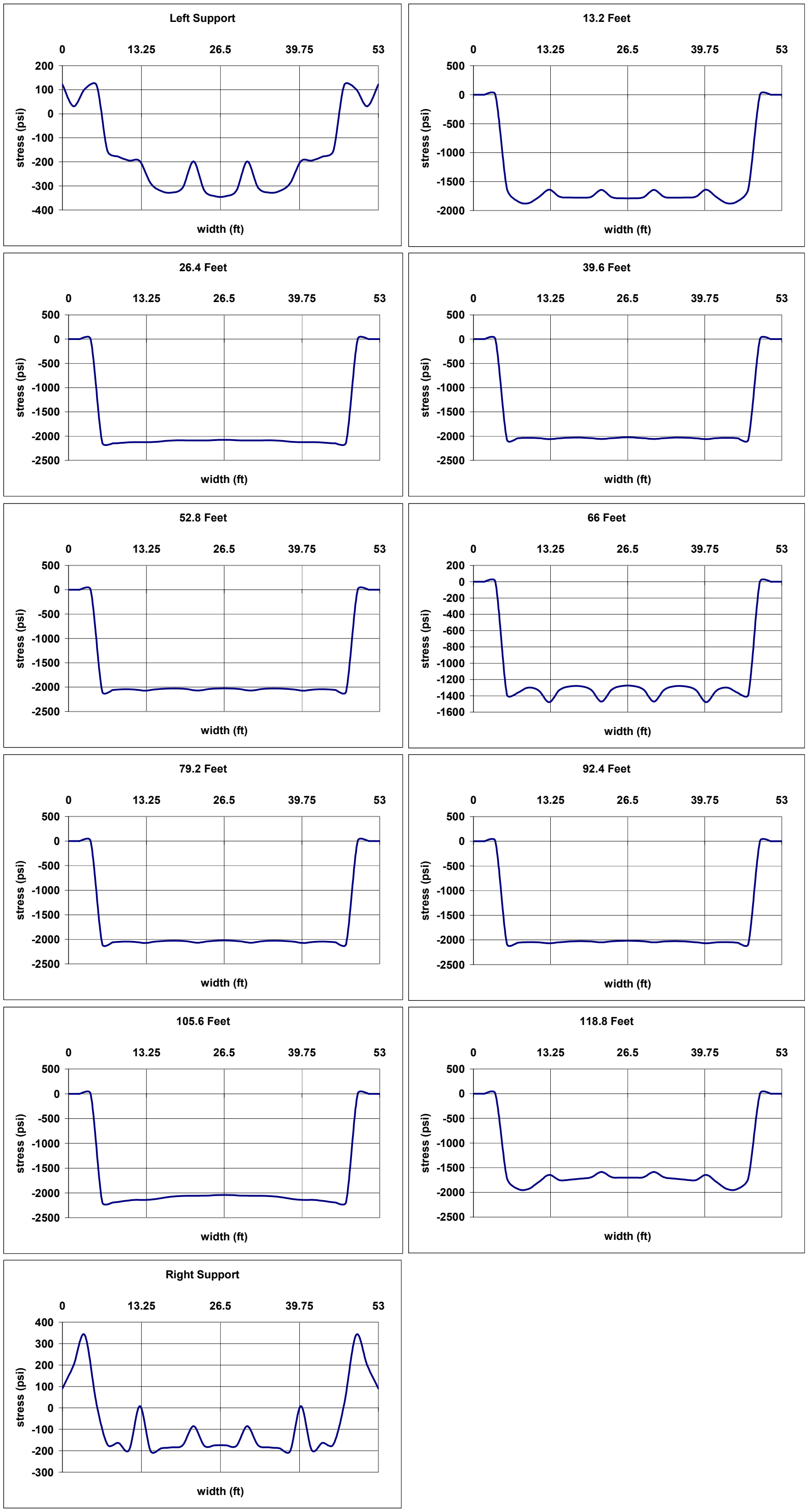

Figure C.22 Bridge G1697S, 60% Deck Removal, Bottom Fiber

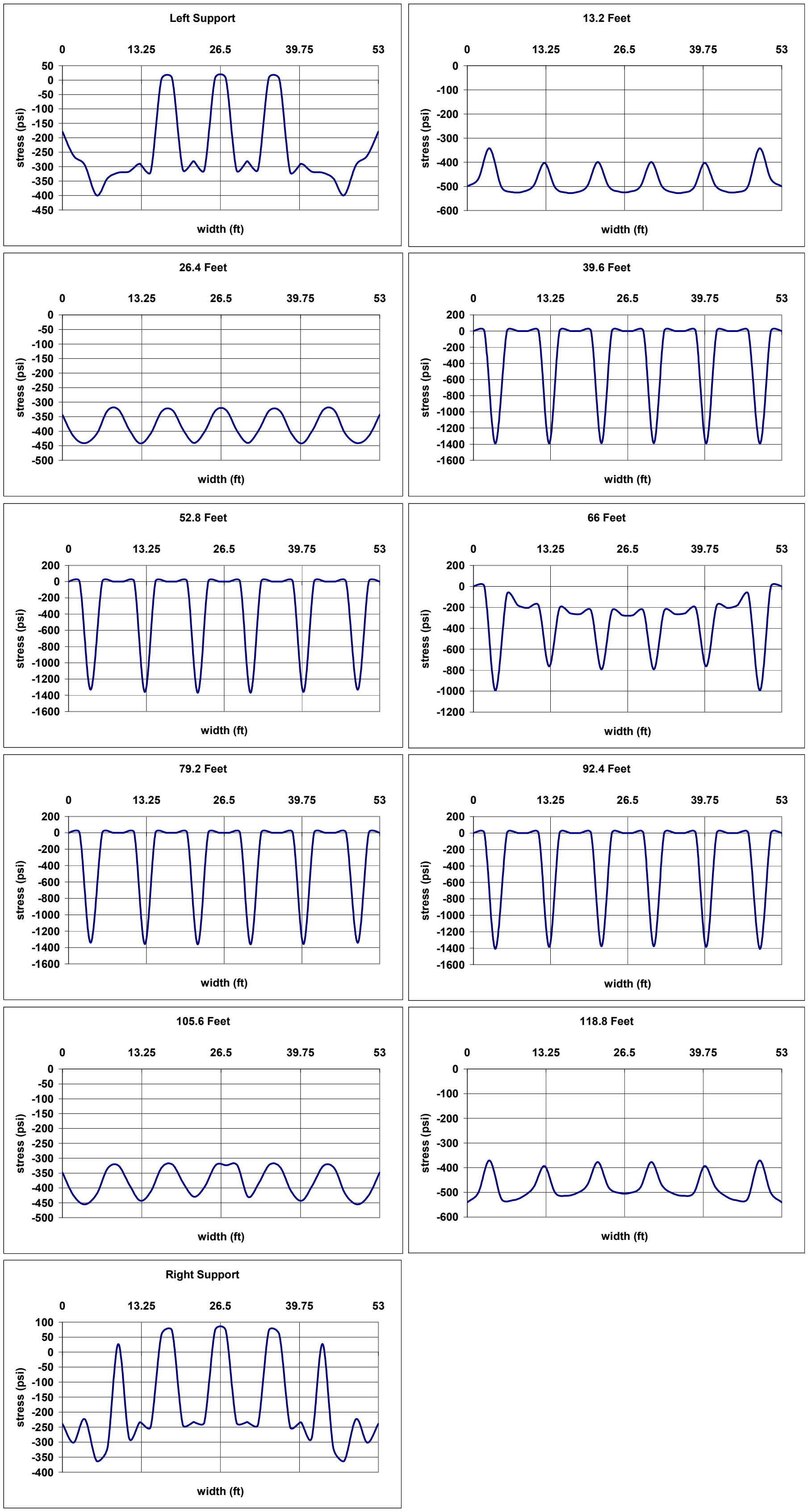

Figure C.23 Bridge G1697S, 50% Deck Removal, Top Fiber

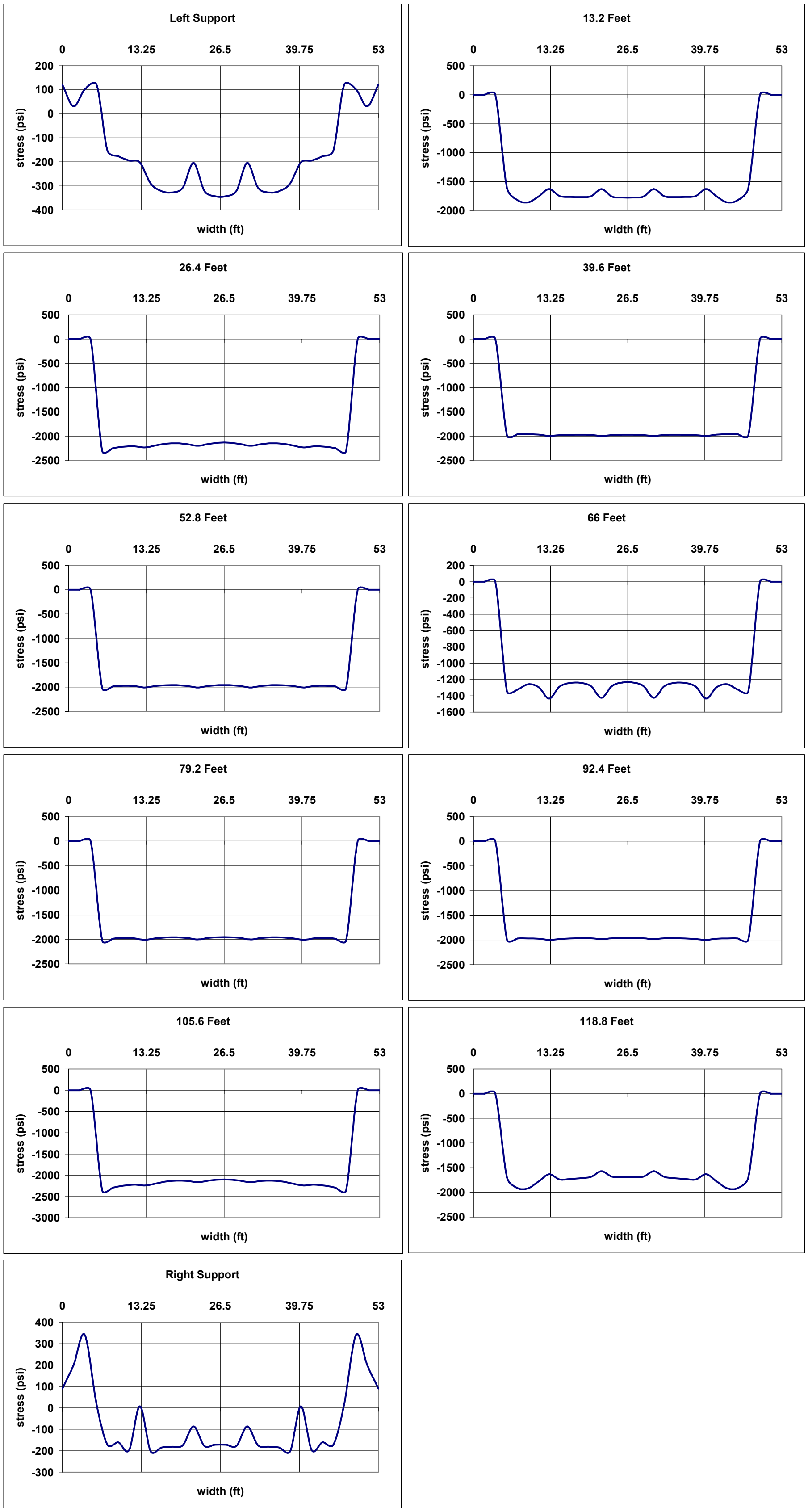

Figure C.24 Bridge G1697S, 50% Deck Removal, Bottom Fiber

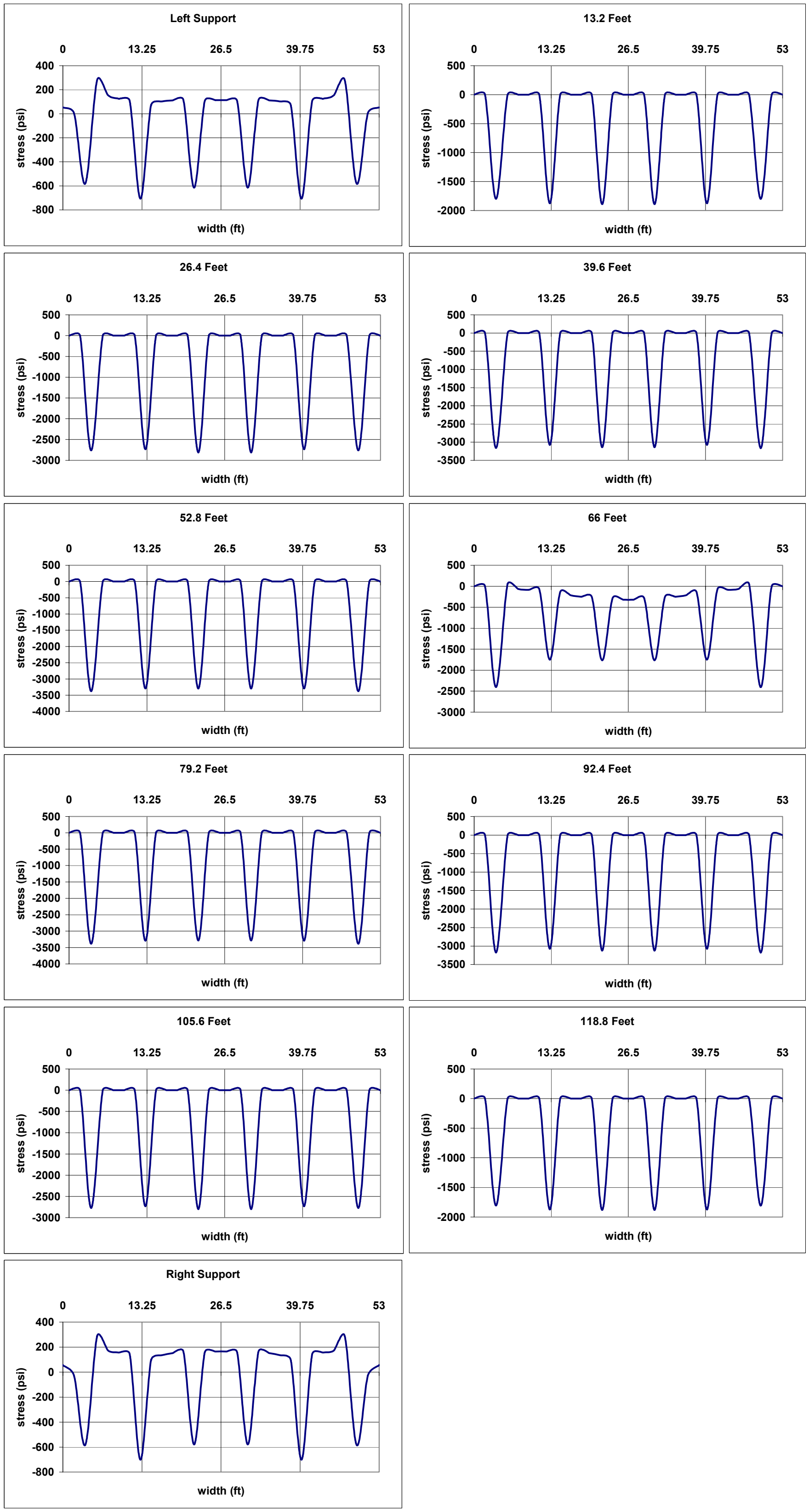

Figure C.25 Bridge G1697S, 600 kips of Additional Prestress, DL+PS+ADL+APS, Top Fiber

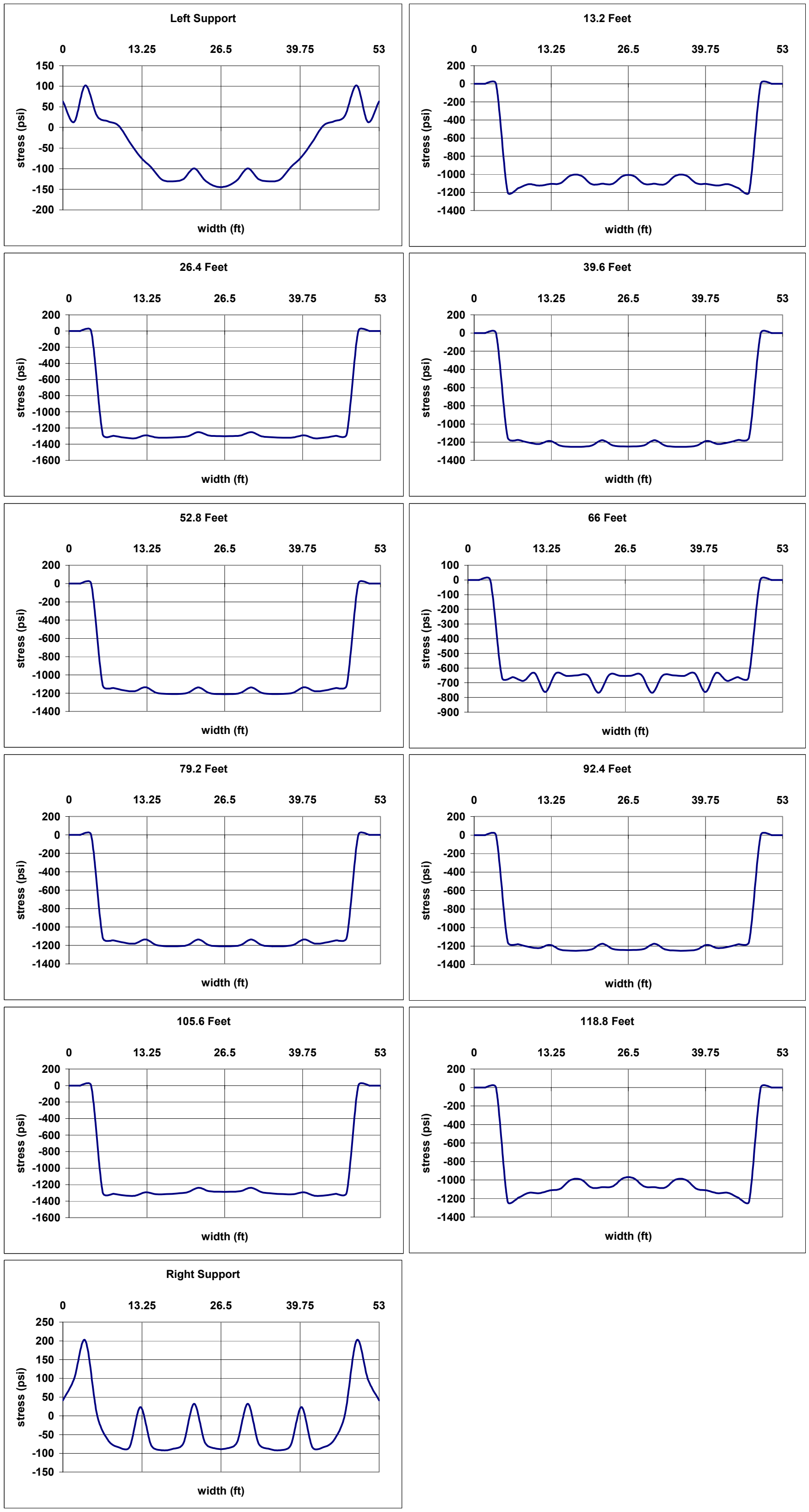

Figure C.26 Bridge G1697S, 600 kips of Additional Prestress, DL+PS+ADL+APS, Bottom Fiber

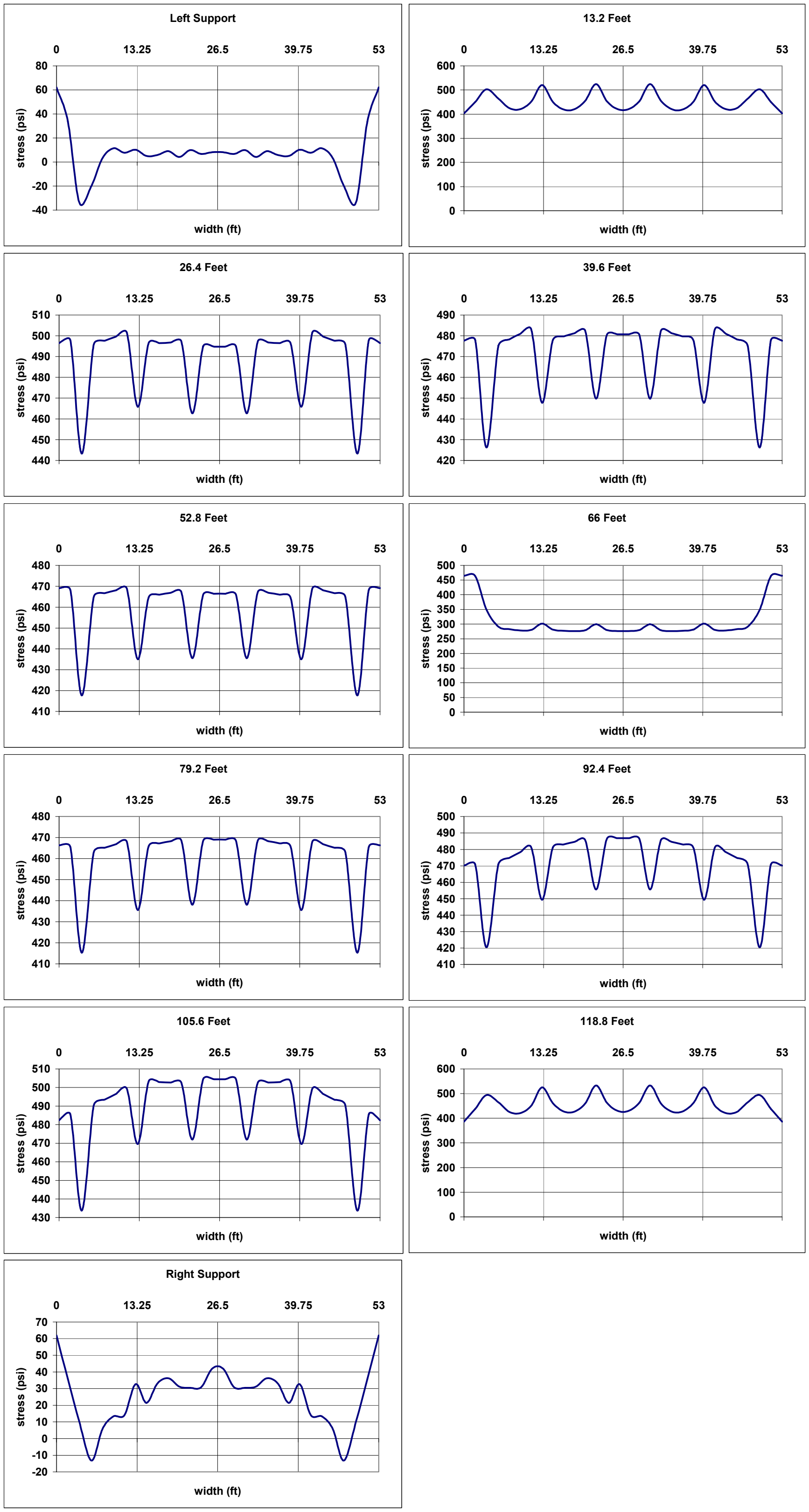

Figure C.27 Bridge G1697S, 600 kips of Additional Prestress, APS, Top Fiber

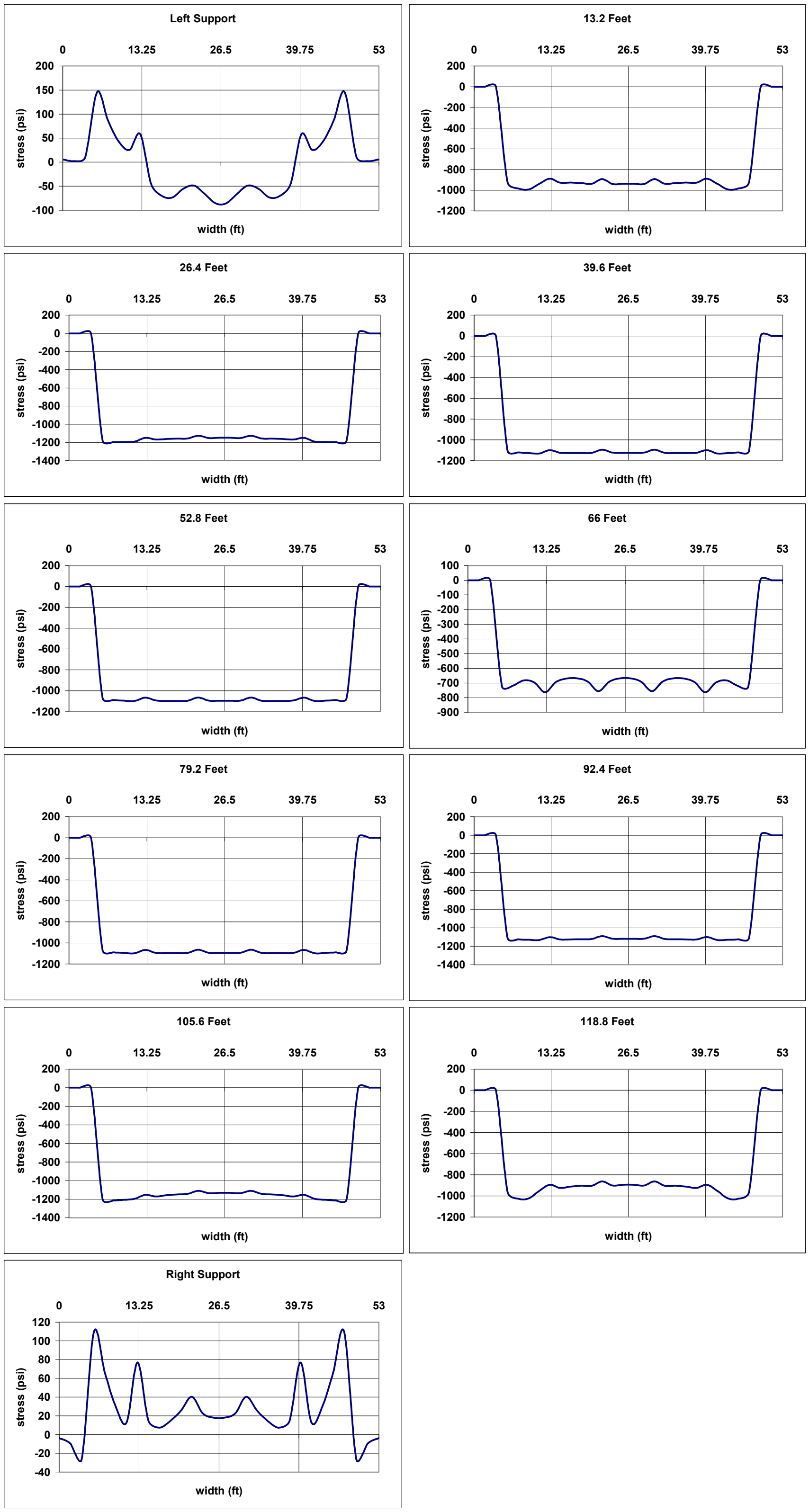

Figure C.28 Bridge G1697S, 600 kips of Additional Prestress, APS, Bottom Fiber

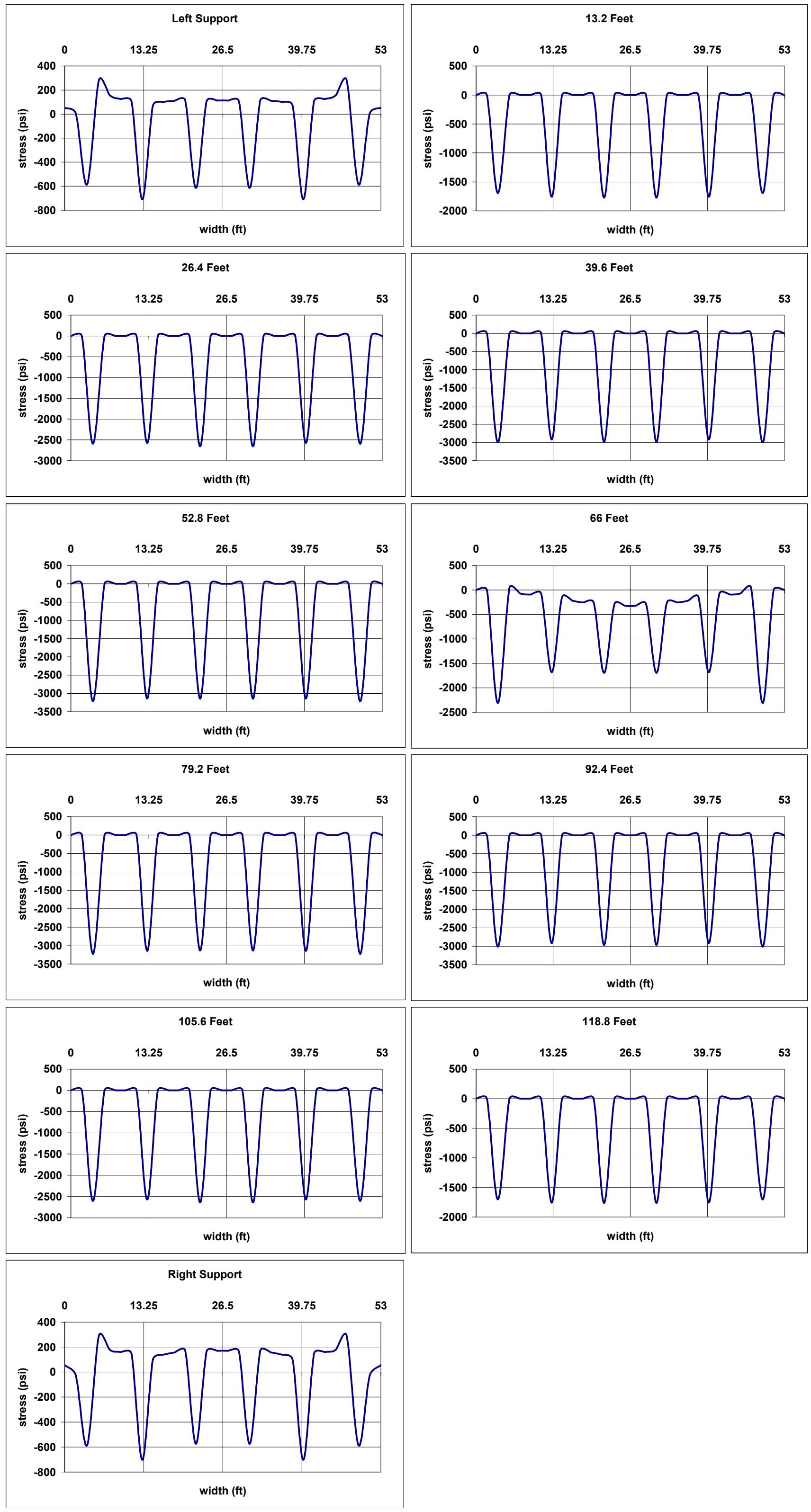

Figure C.29 Bridge G1697S, 600 kips of Additional Prestress, DL+PS+ADL+APS, Top Fiber

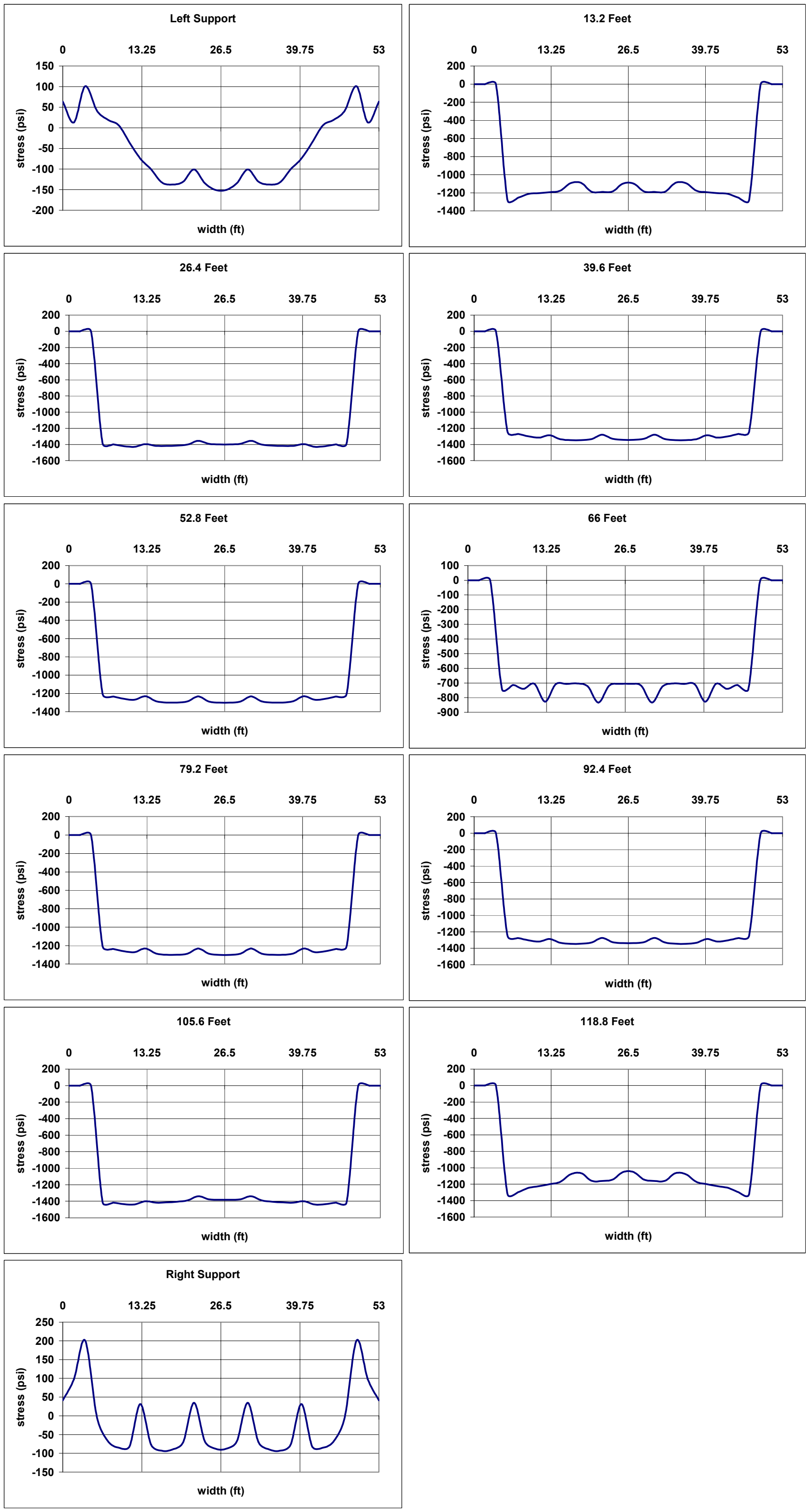

Figure C.30 Bridge G1697S, 650 kips of Additional Prestress, DL+PS+ADL+APS, Bottom Fiber

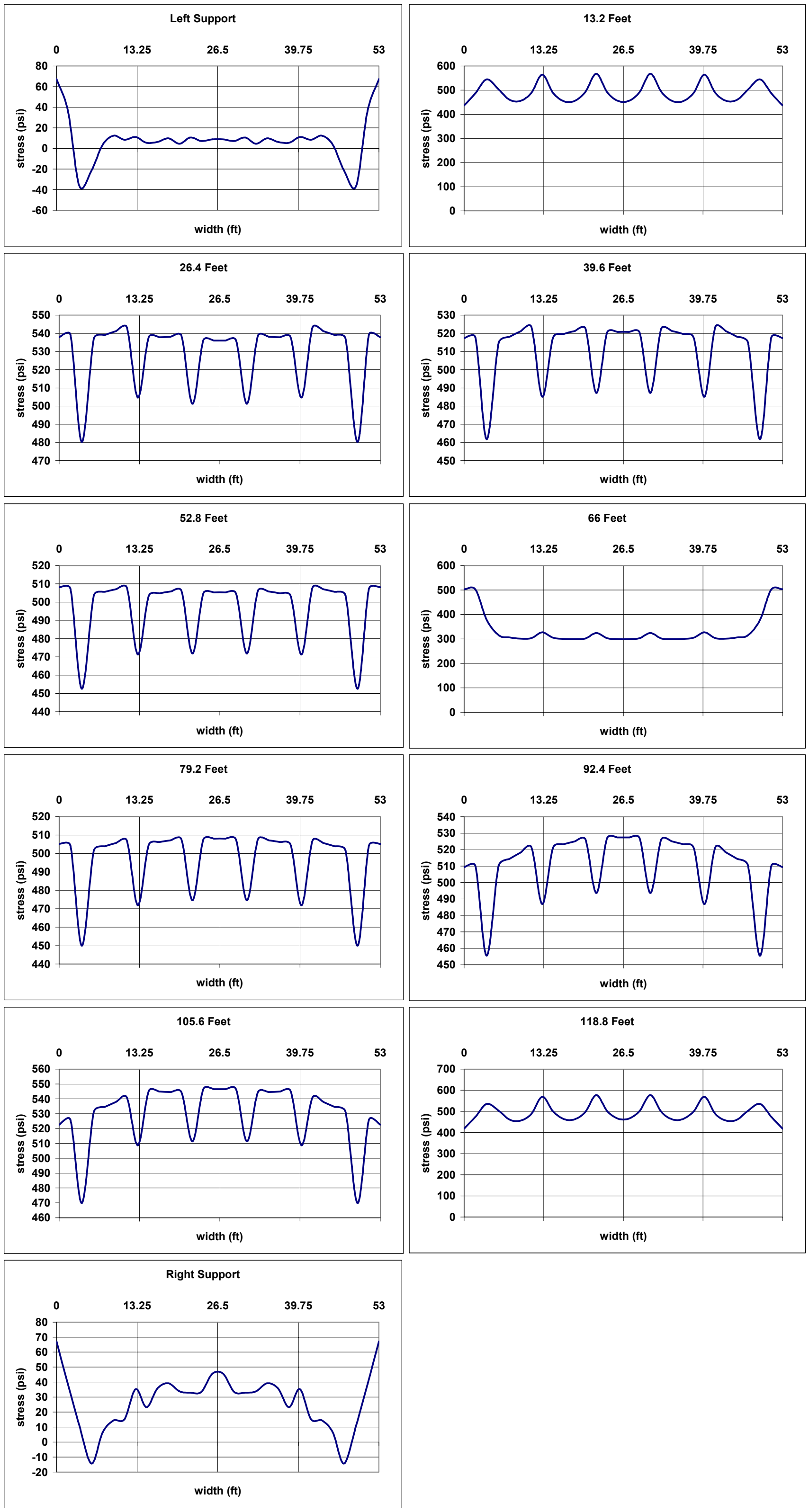

Figure C.31 Bridge G1697S, 650 kips of Additional Prestress, APS, Top Fiber

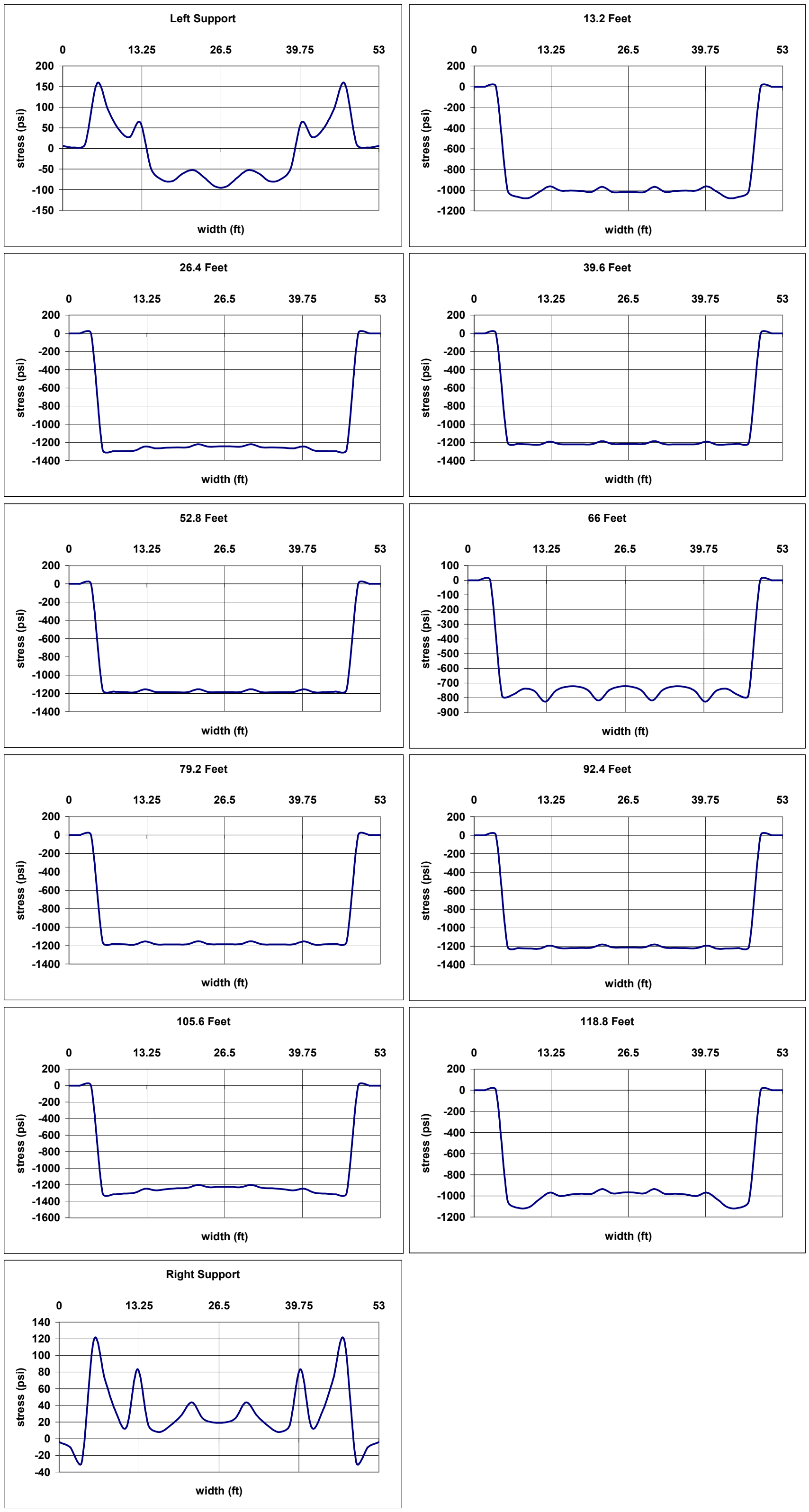

Figure C.32 Bridge G1697S, 650 kips of Additional Prestress, APS, Bottom Fiber

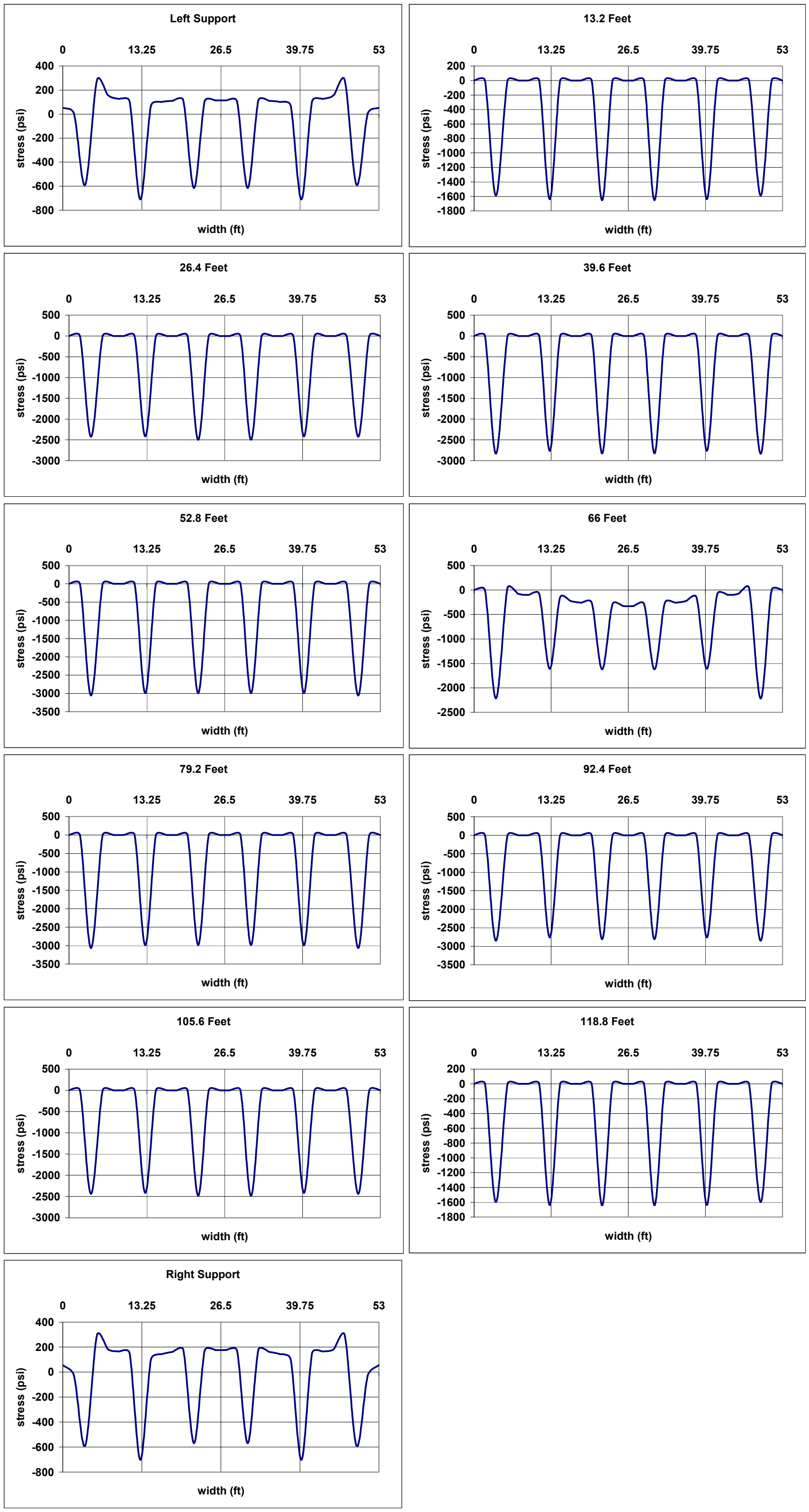

Figure C.33 Bridge G1697S, 700 kips of Additional Prestress, DL+PS+ADL+APS, Top Fiber

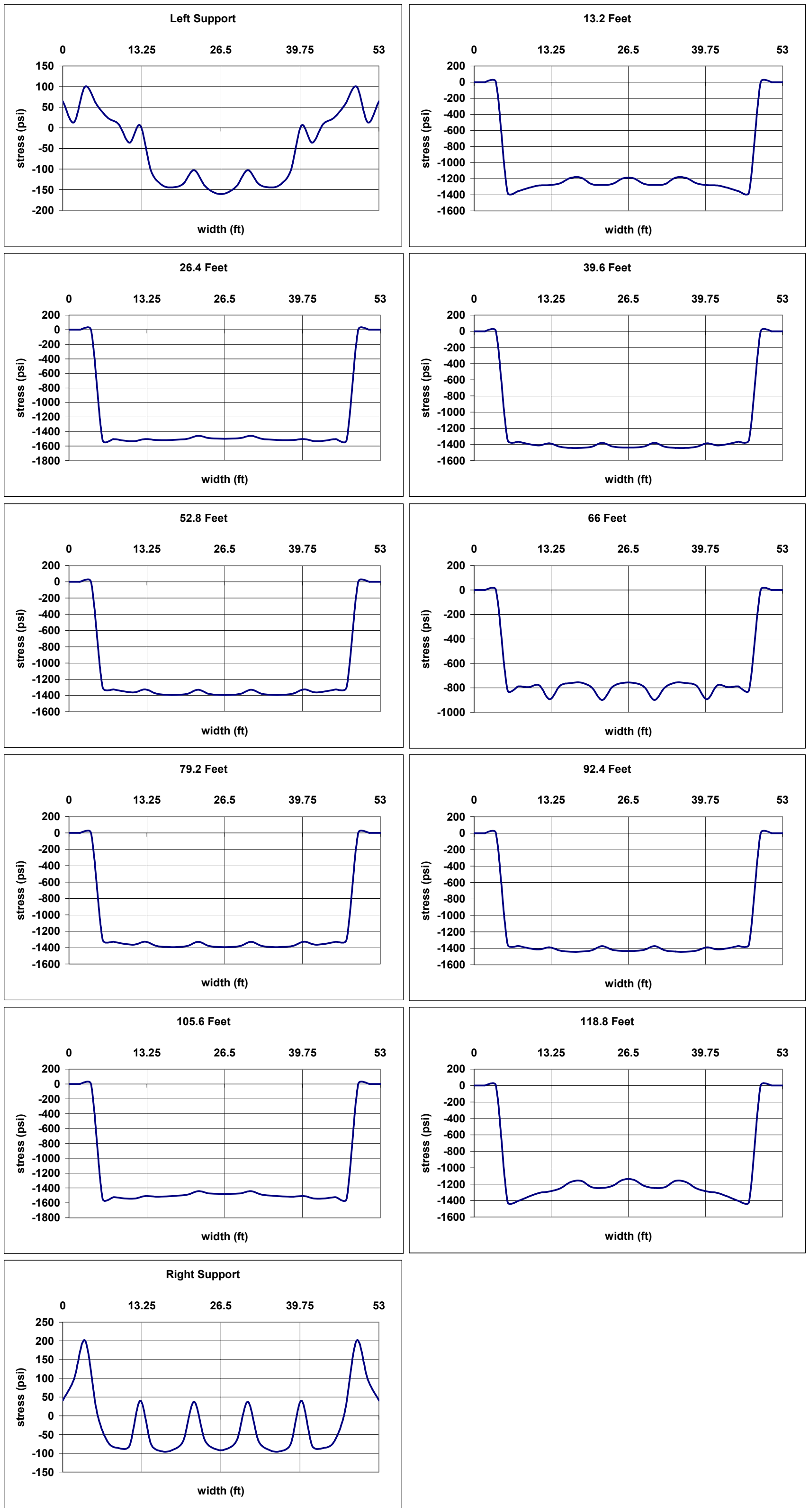

Figure C.34 Bridge G1697S, 700 kips of Additional Prestress, DL+PS+ADL+APS, Bottom Fiber

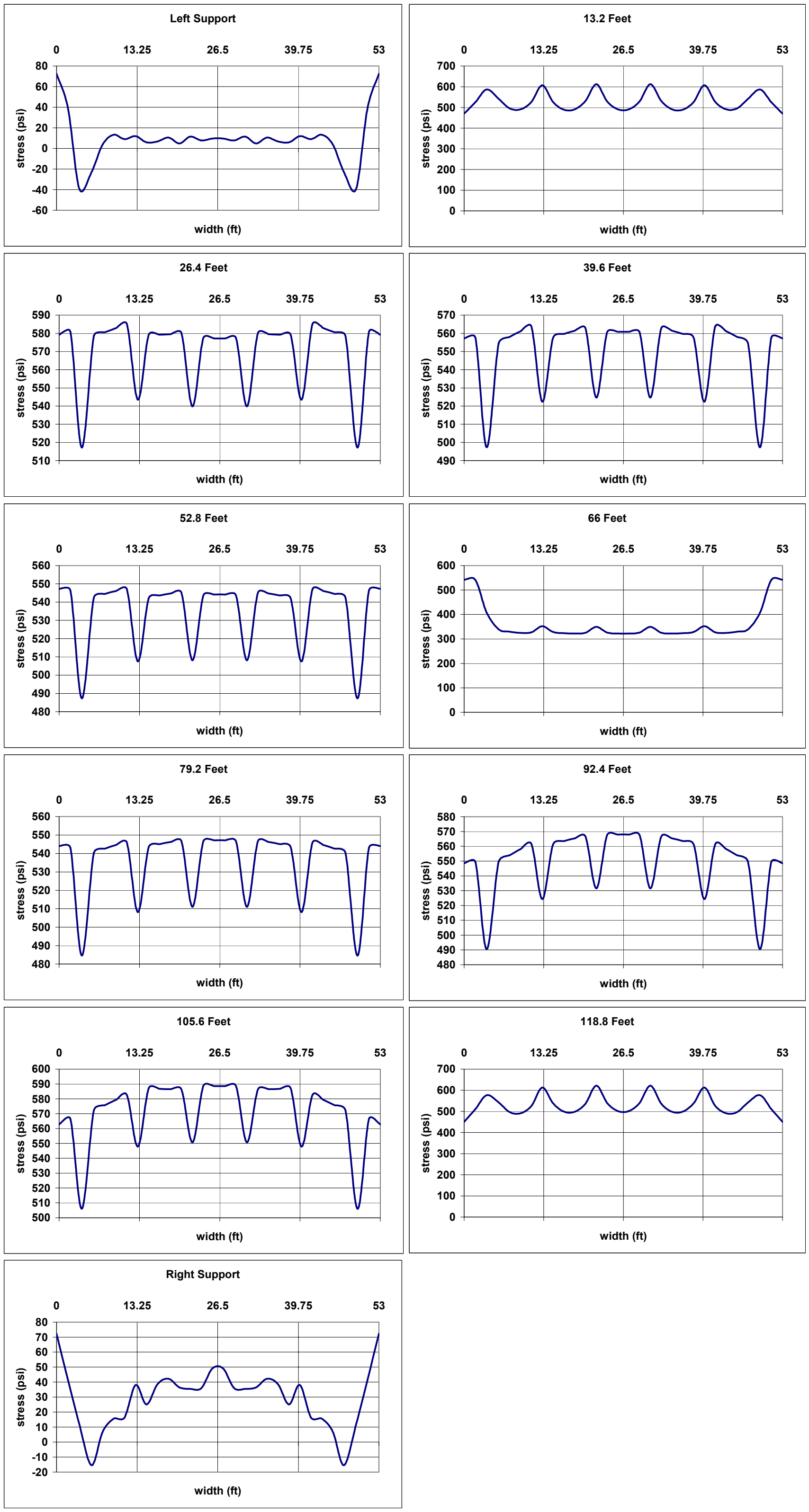

Figure C.35 Bridge G1697S, 700 kips of Additional Prestress, APS, Top Fiber

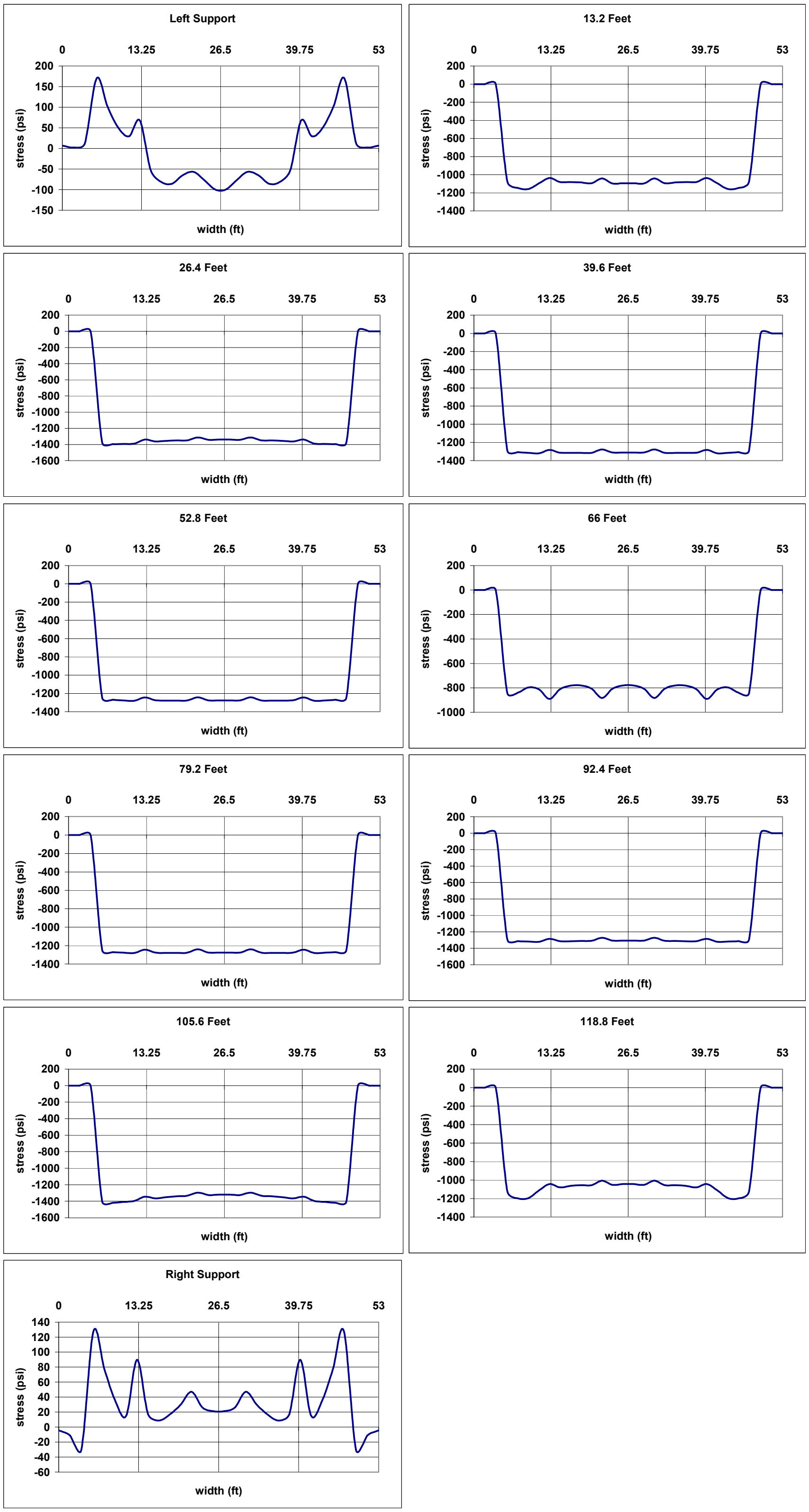

Figure C.36 Bridge G1697S, 700 kips of Additional Prestress, APS, Bottom Fiber

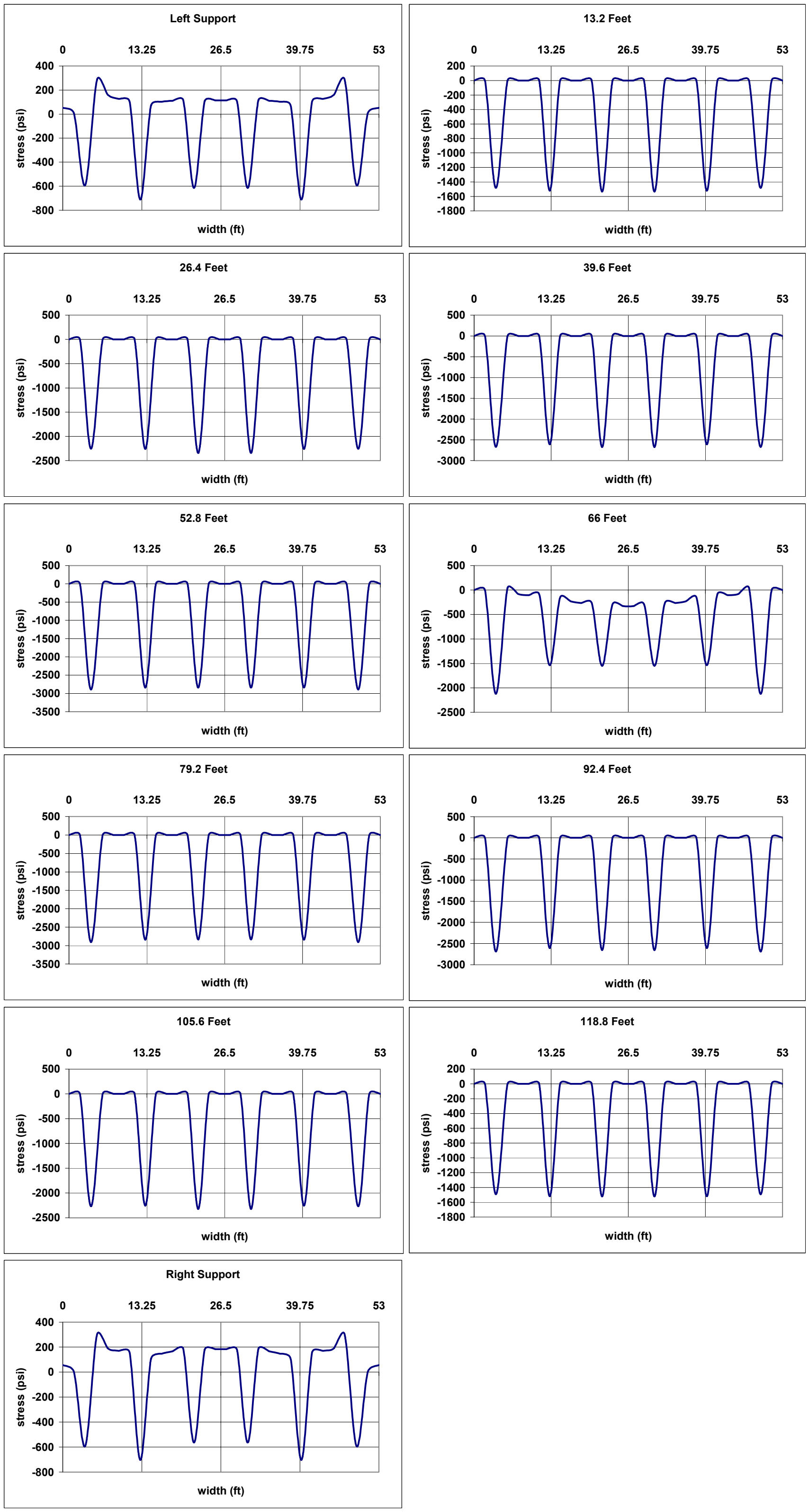

Figure C.37 Bridge G1697S, 750 kips of Additional Prestress, DL+PS+ADL+APS, Top Fiber

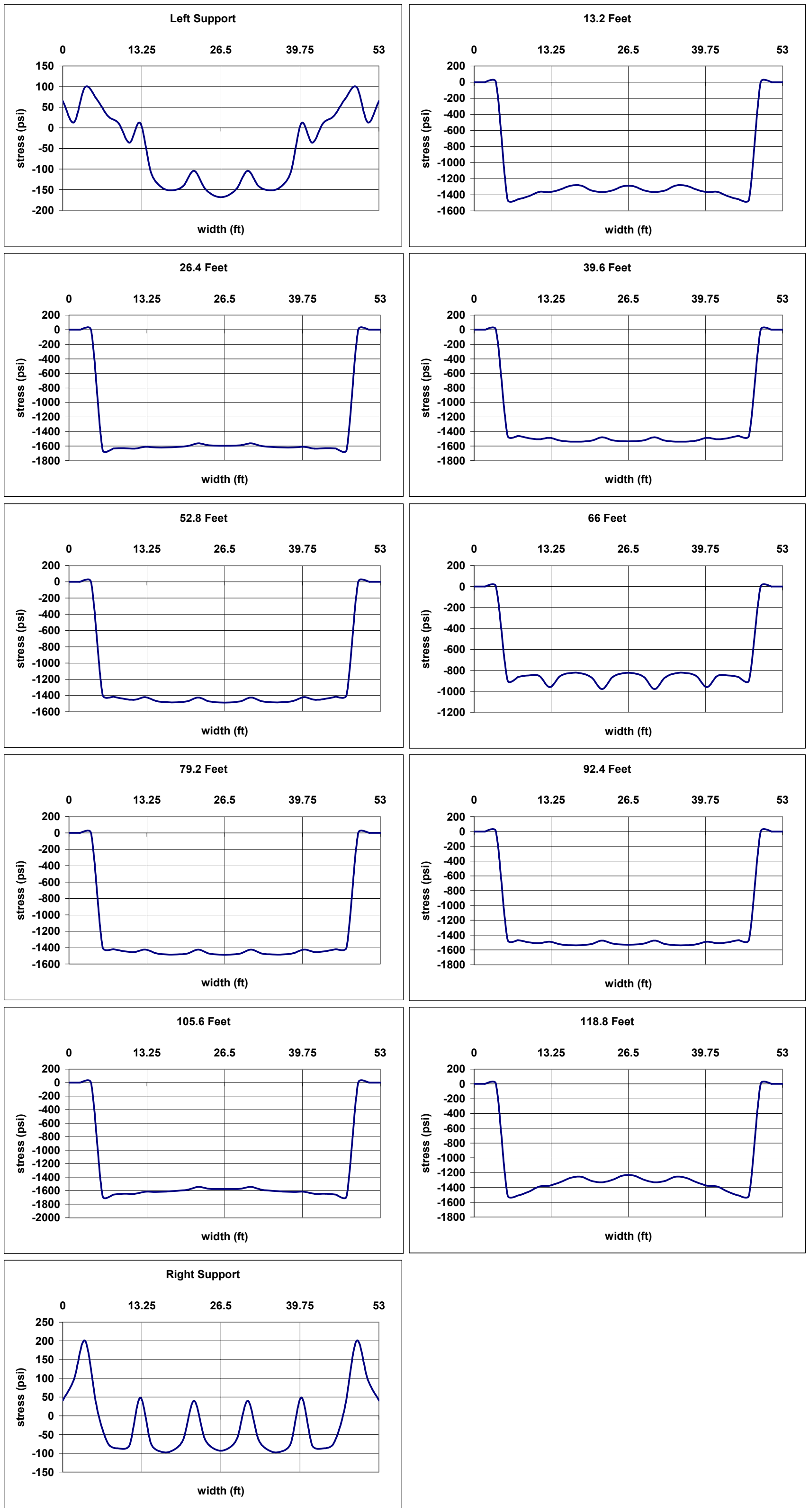

Figure C.38 Bridge G1697S, 750 kips of Additional Prestress, DL+PS+ADL+APS, Bottom Fiber

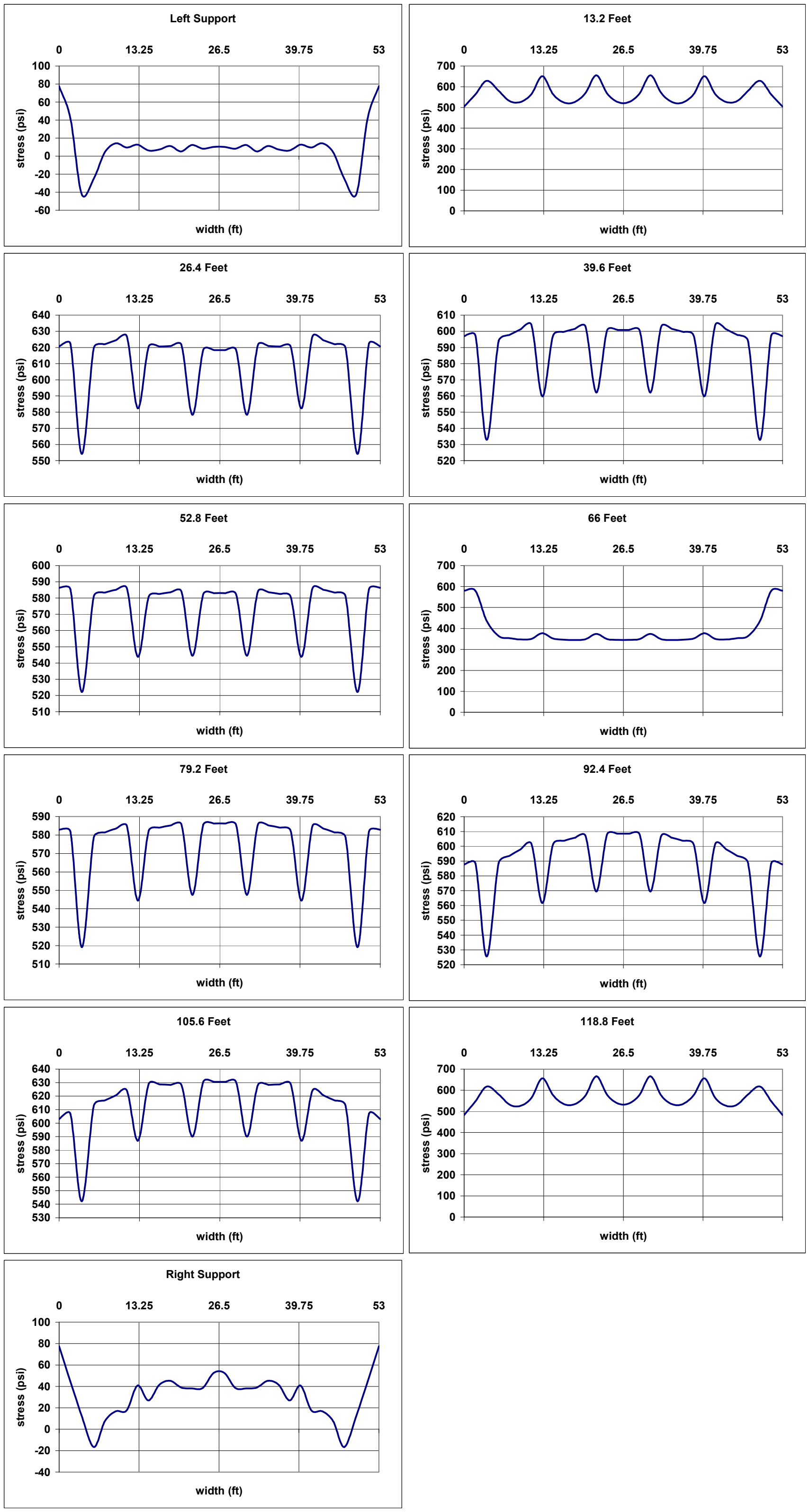

Figure C.39 Bridge G1697S, 750 kips of Additional Prestress, APS, Top Fiber

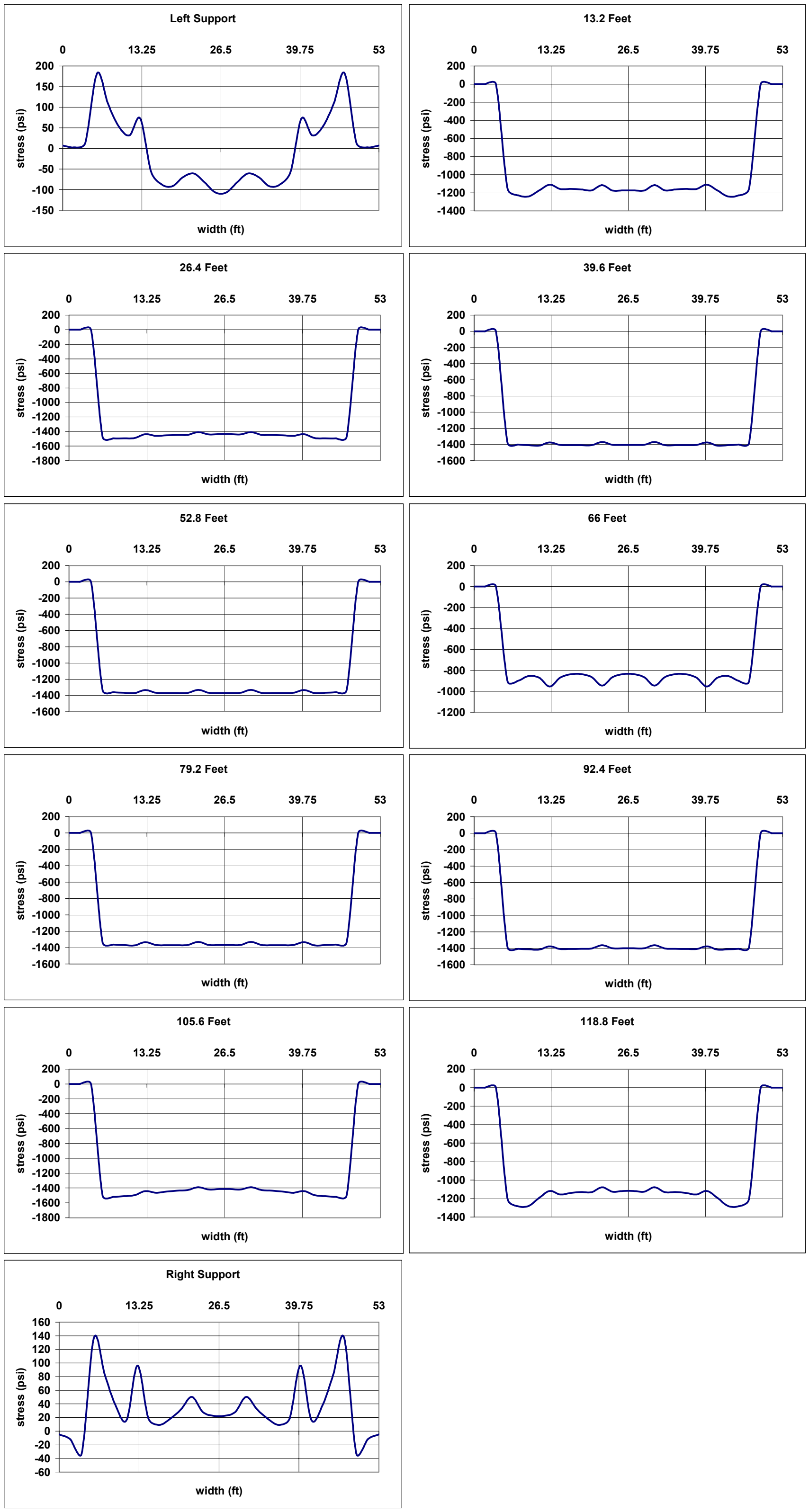

Figure C.40 Bridge G1697S, 750 kips of Additional Prestress, APS, Bottom Fiber

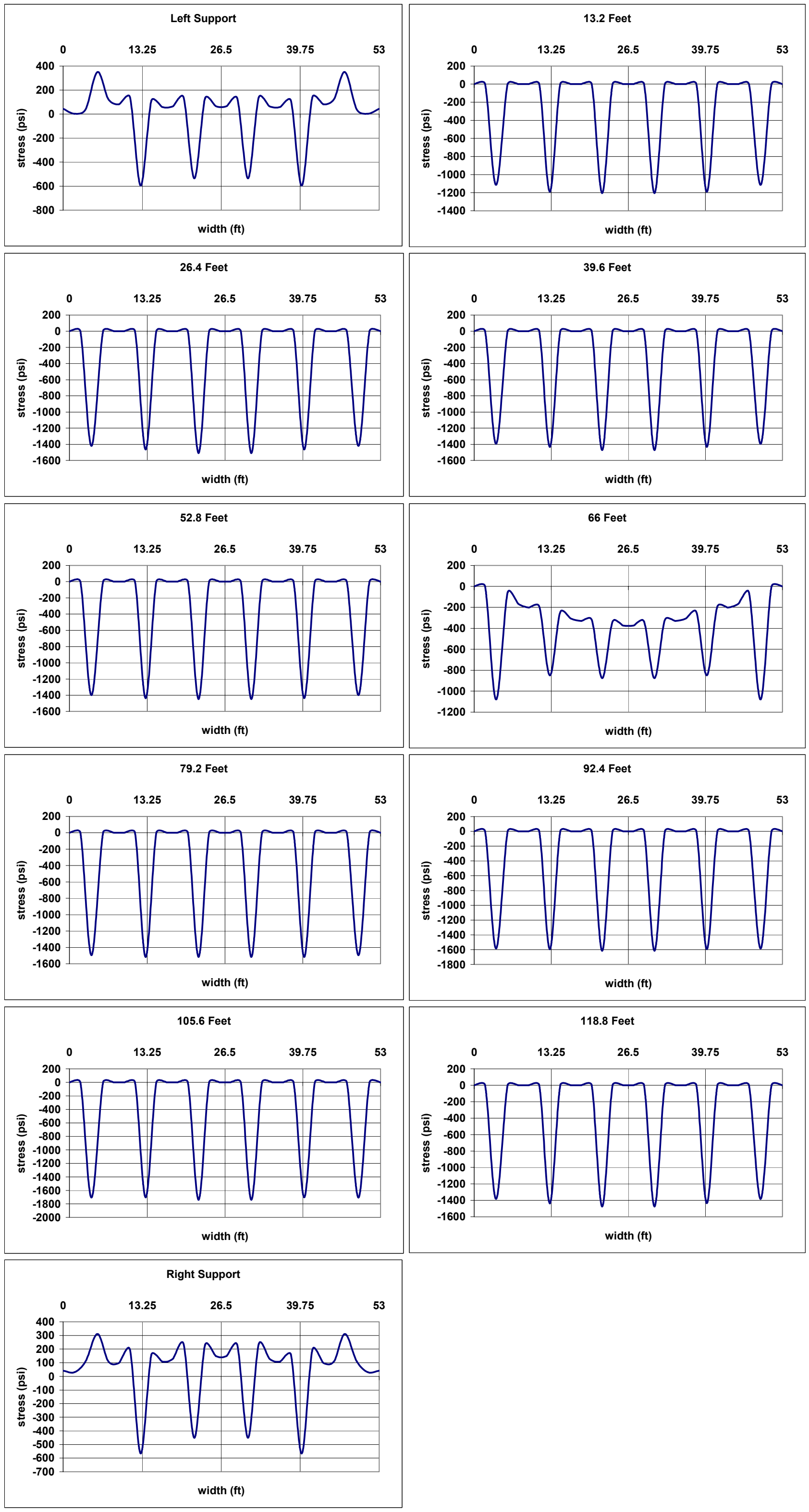

Figure C.41 Bridge G1697S, 0 feet from the Abutment, Top Fiber

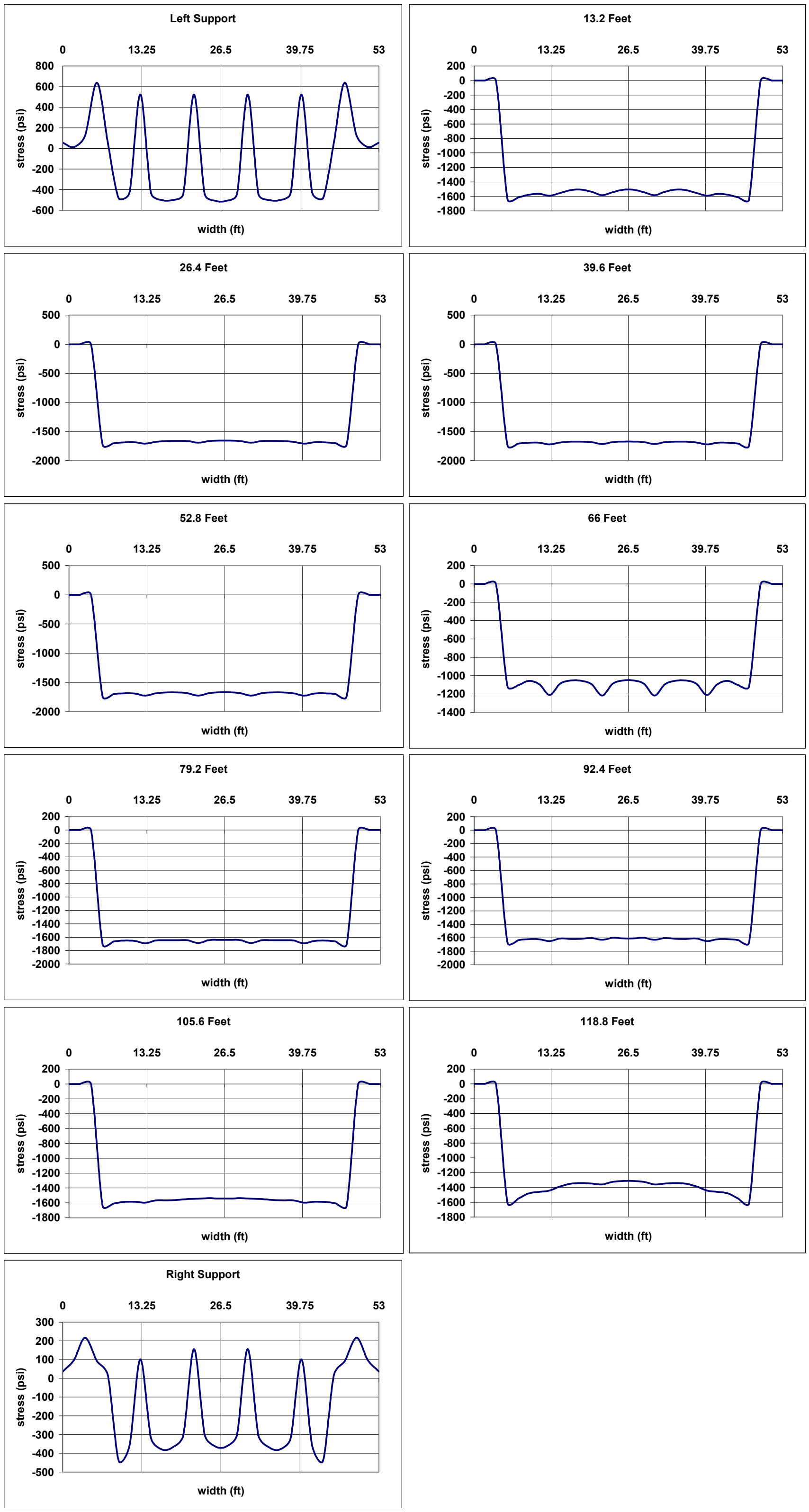

Figure C.42 Bridge G1697S, 0 feet from the Abutment, Bottom Fiber

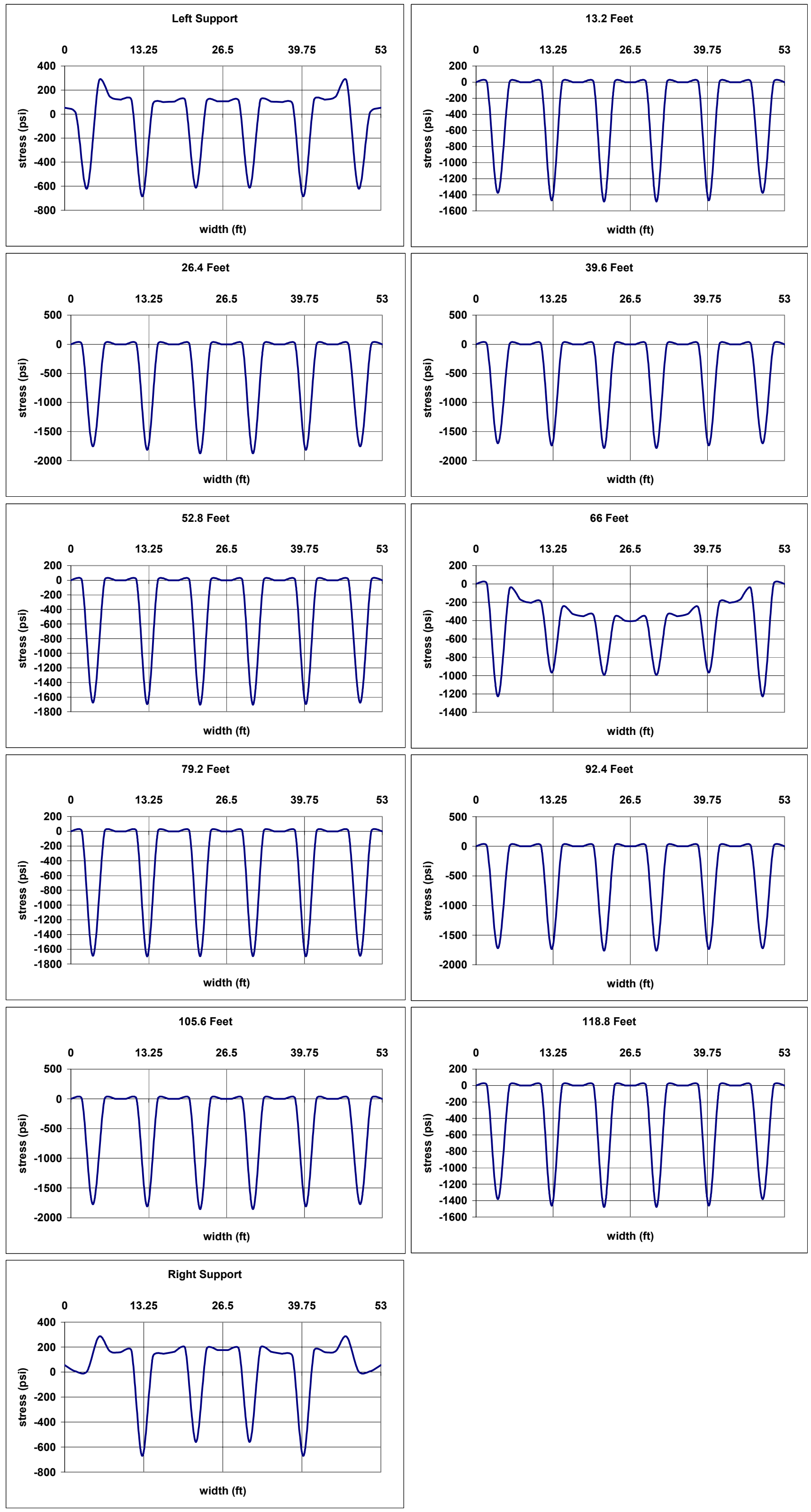

Figure C.43 Bridge G1697S, 5.66 feet from the Abutment, Top Fiber

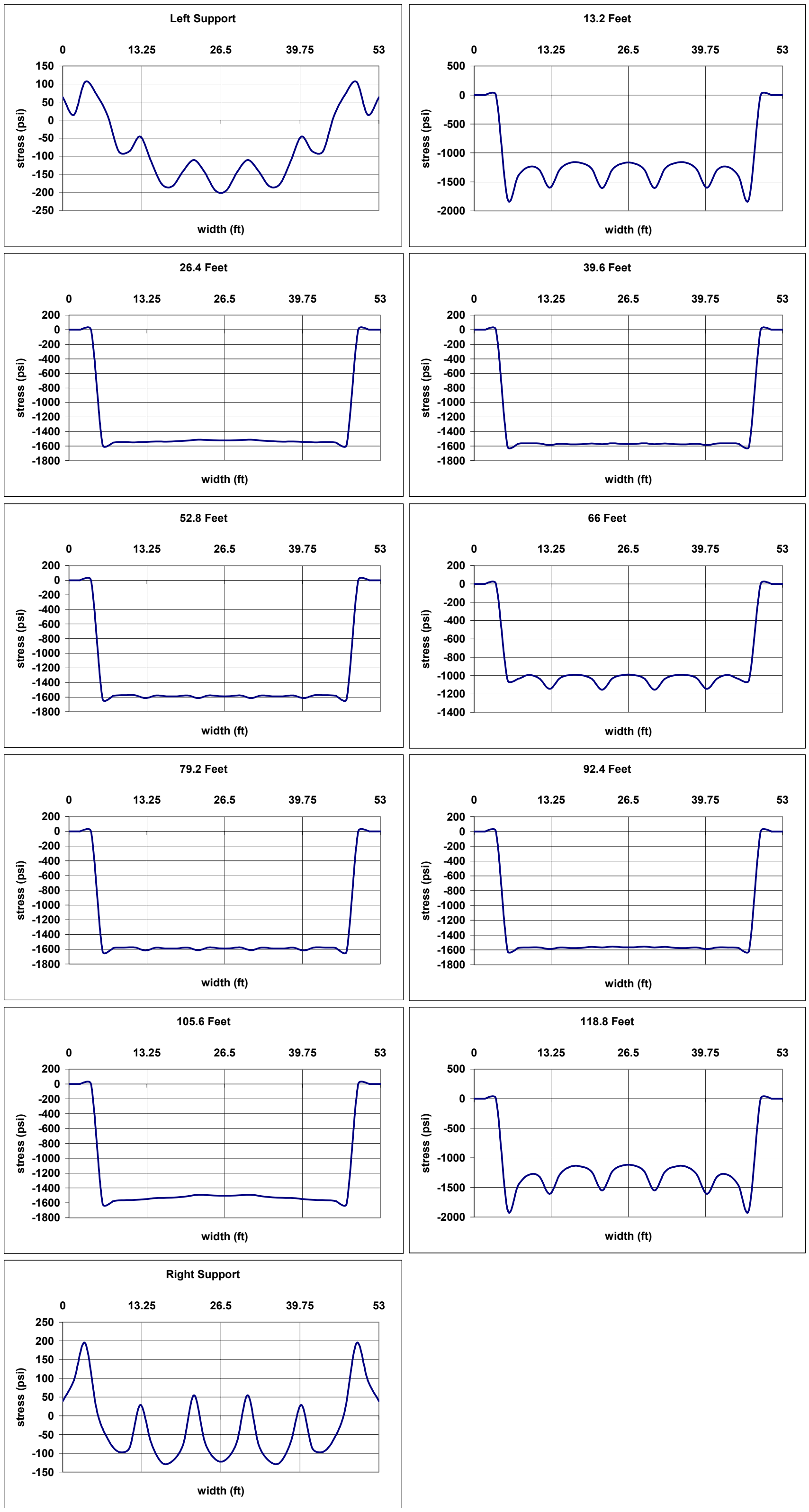

Figure C.44 Bridge G1697S, 5.66 feet from the Abutment, Bottom Fiber

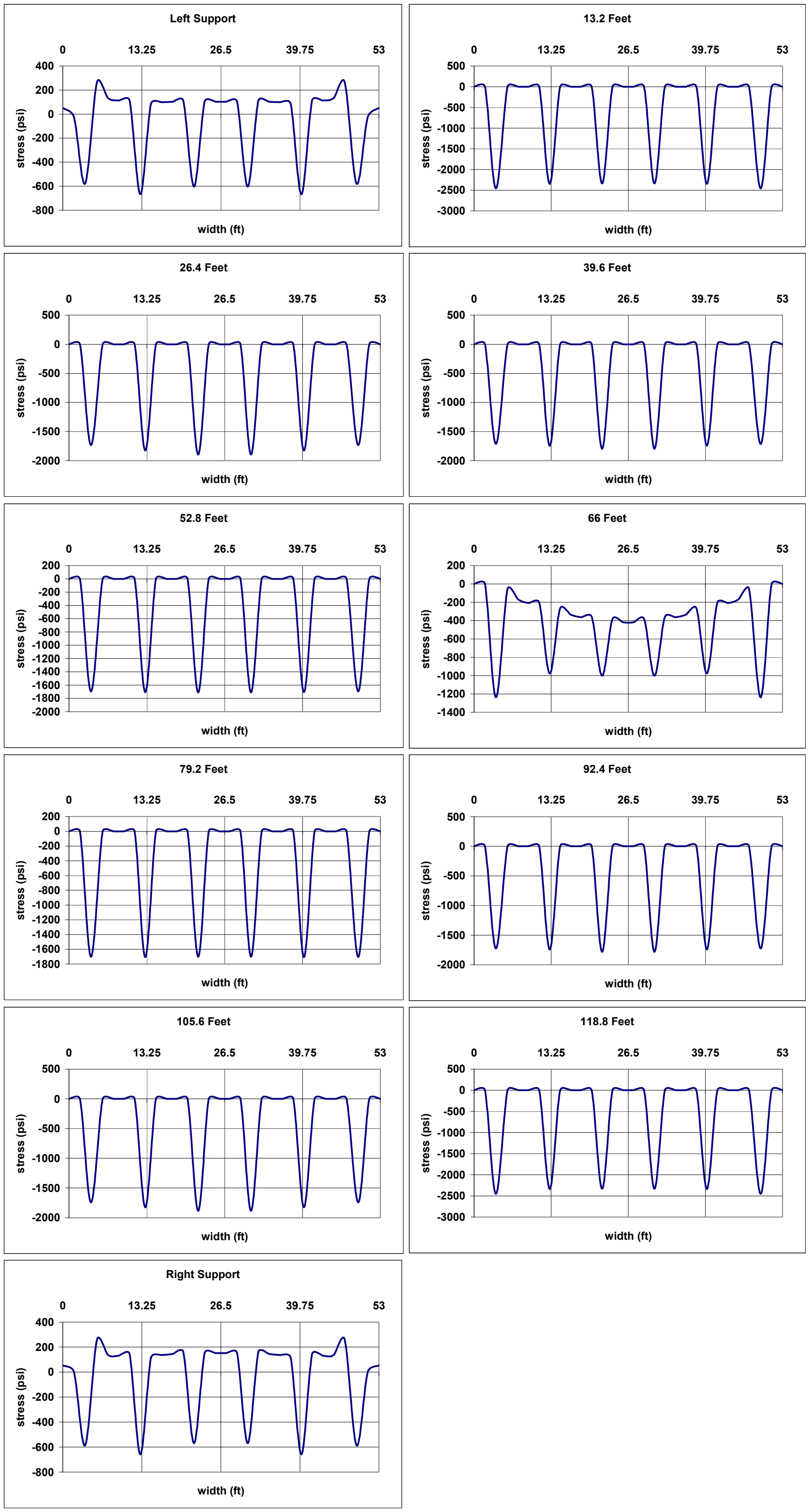

Figure C.45 Bridge G1697S, 11.31 feet from the Abutment, Top Fiber

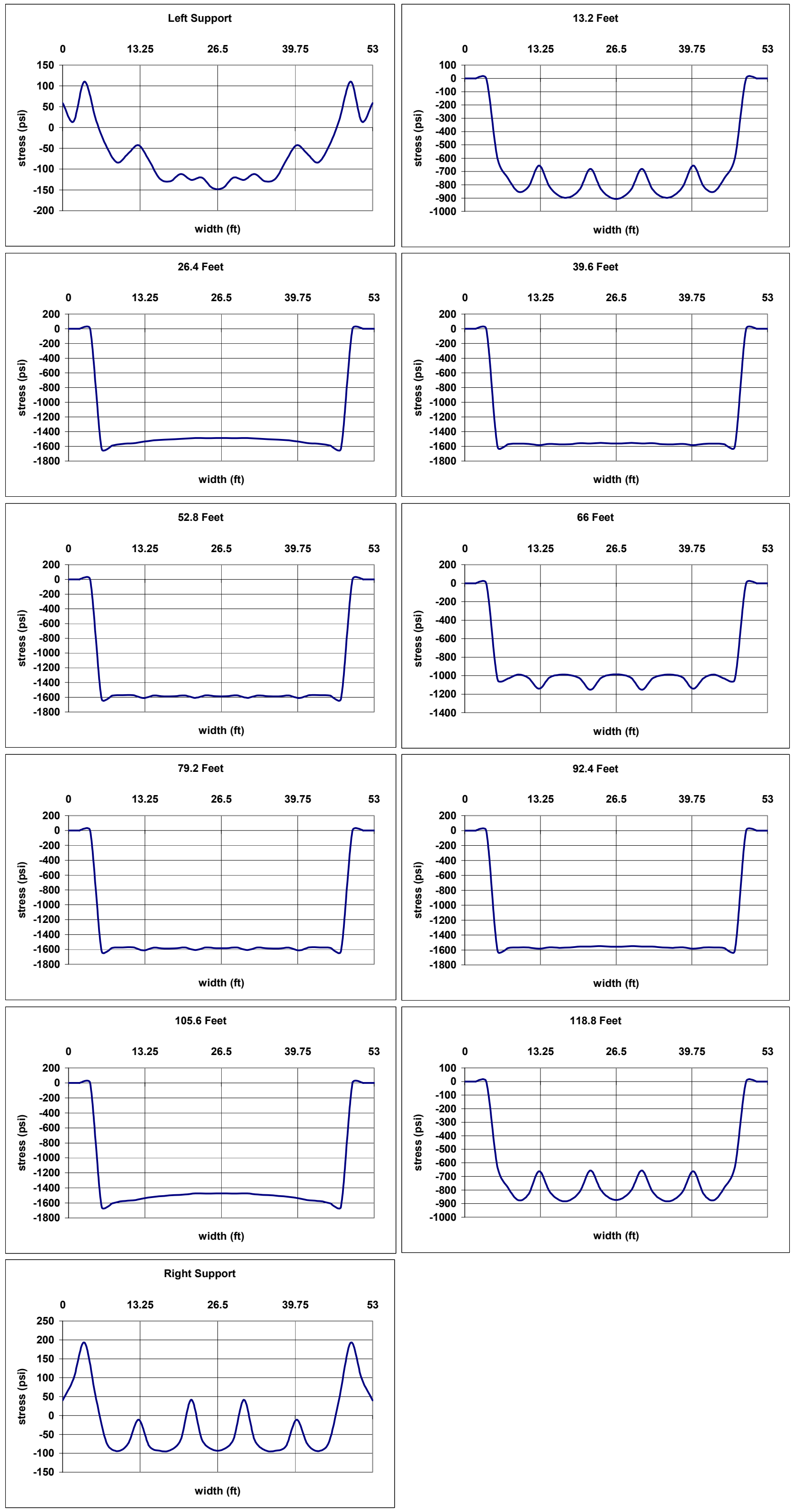

Figure C.46 Bridge G1697S, 11.31 feet from the Abutment, Bottom Fiber

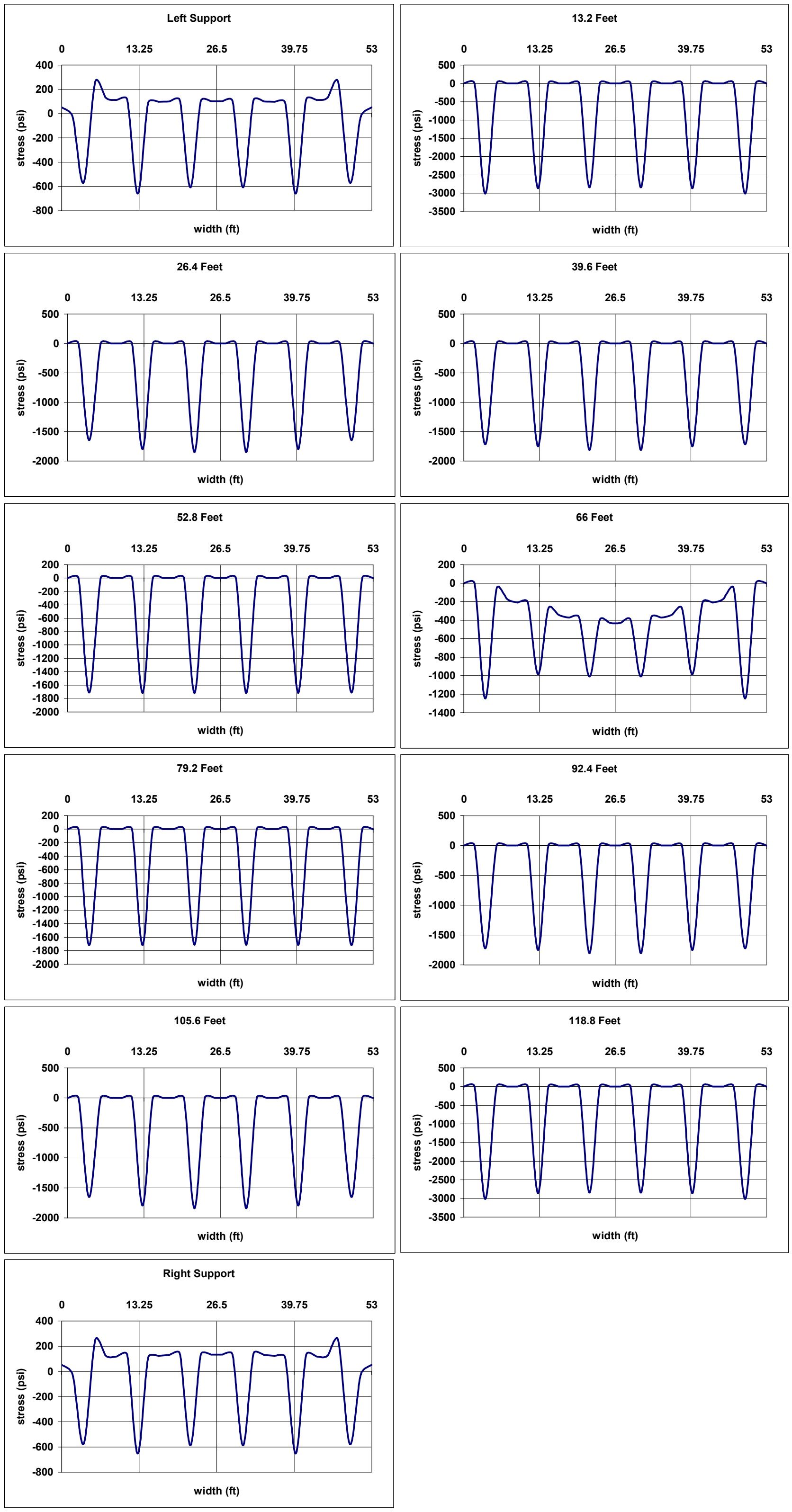

Figure C.47 Bridge G1697S, 16.97 feet from the Abutment, Top Fiber

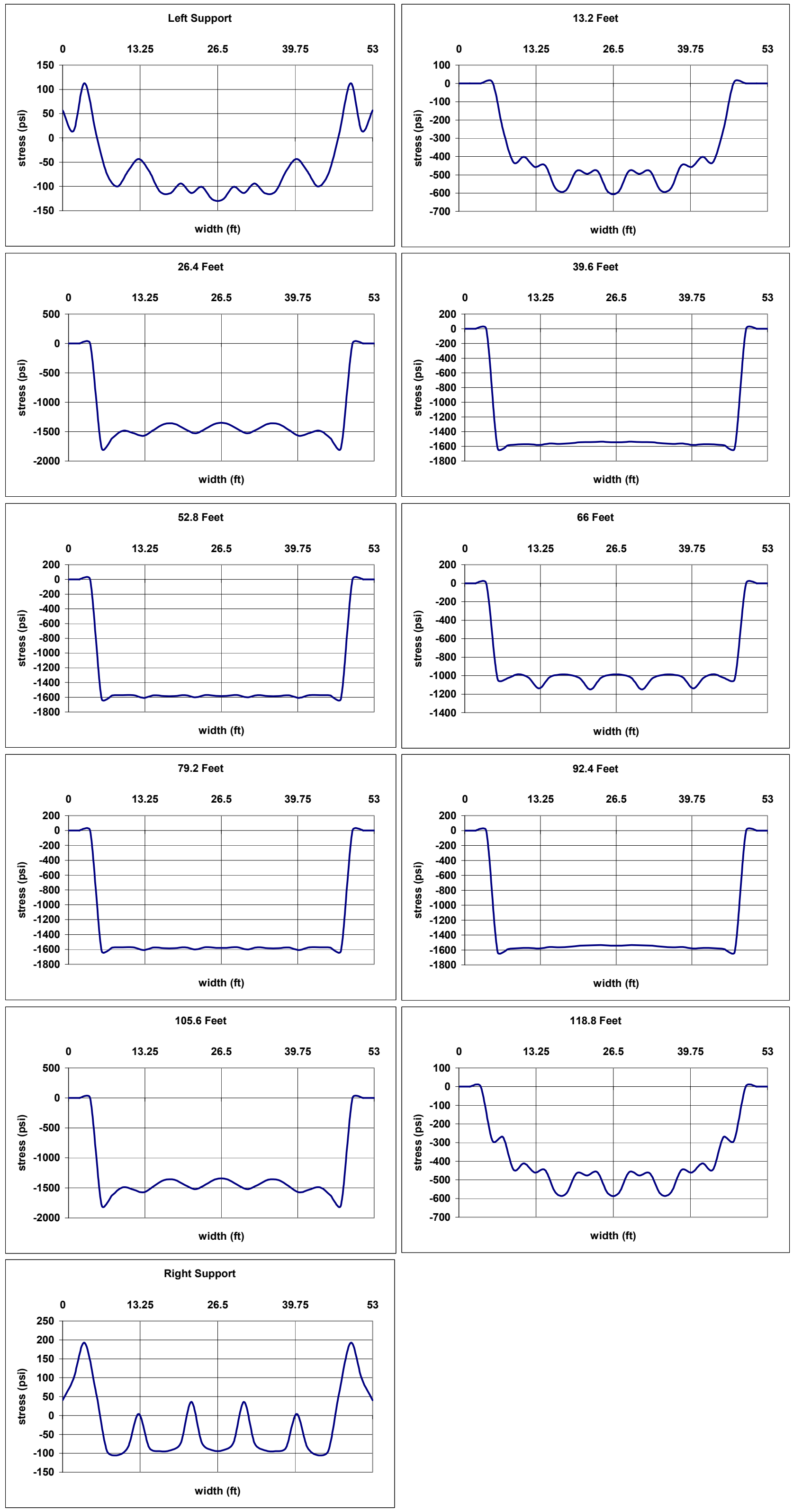

Figure C.48 Bridge G1697S, 16.97 feet from the Abutment, Bottom Fiber

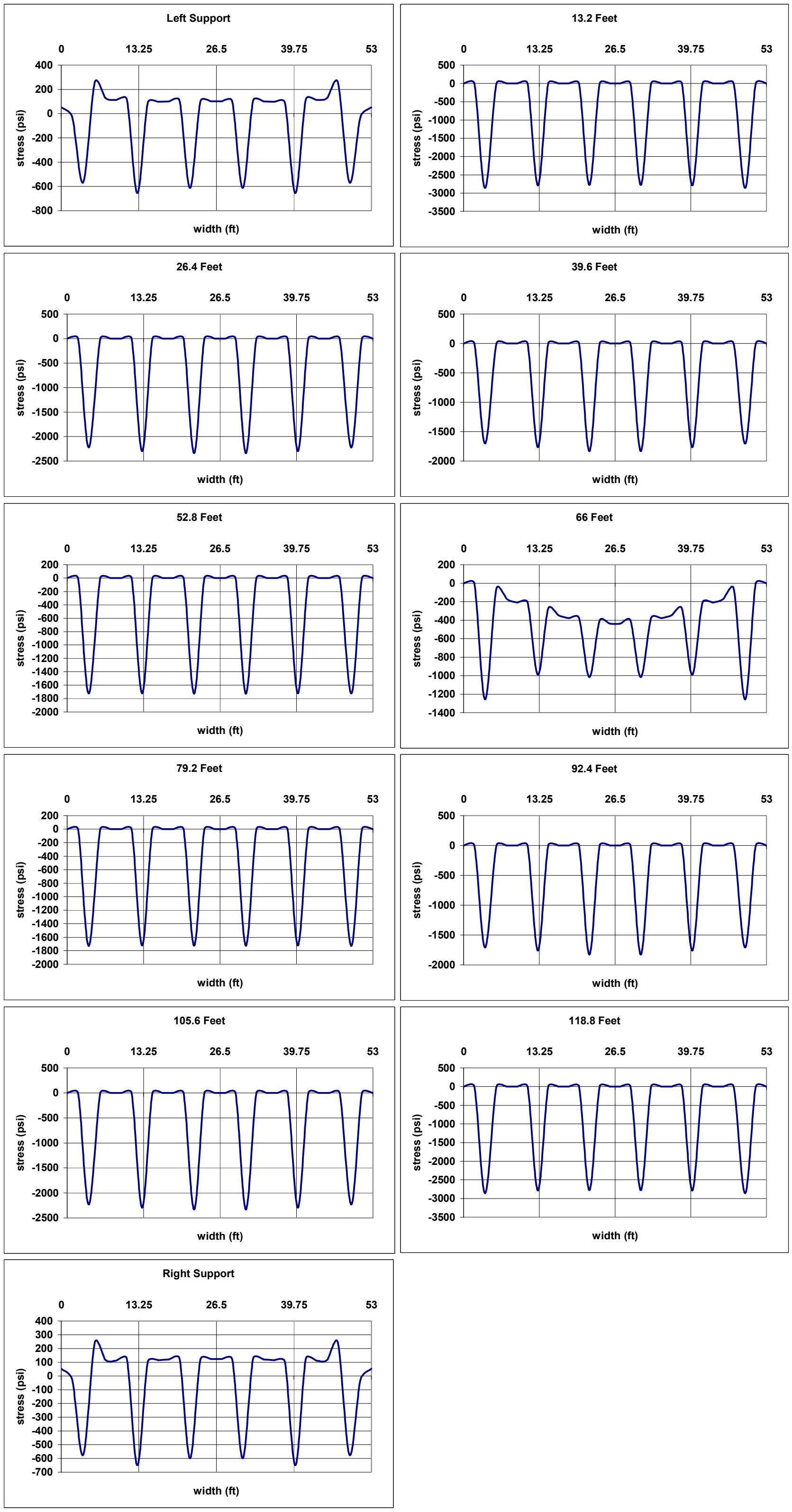

Figure C.49 Bridge G1697S, 22.63 feet from the Abutment, Top Fiber

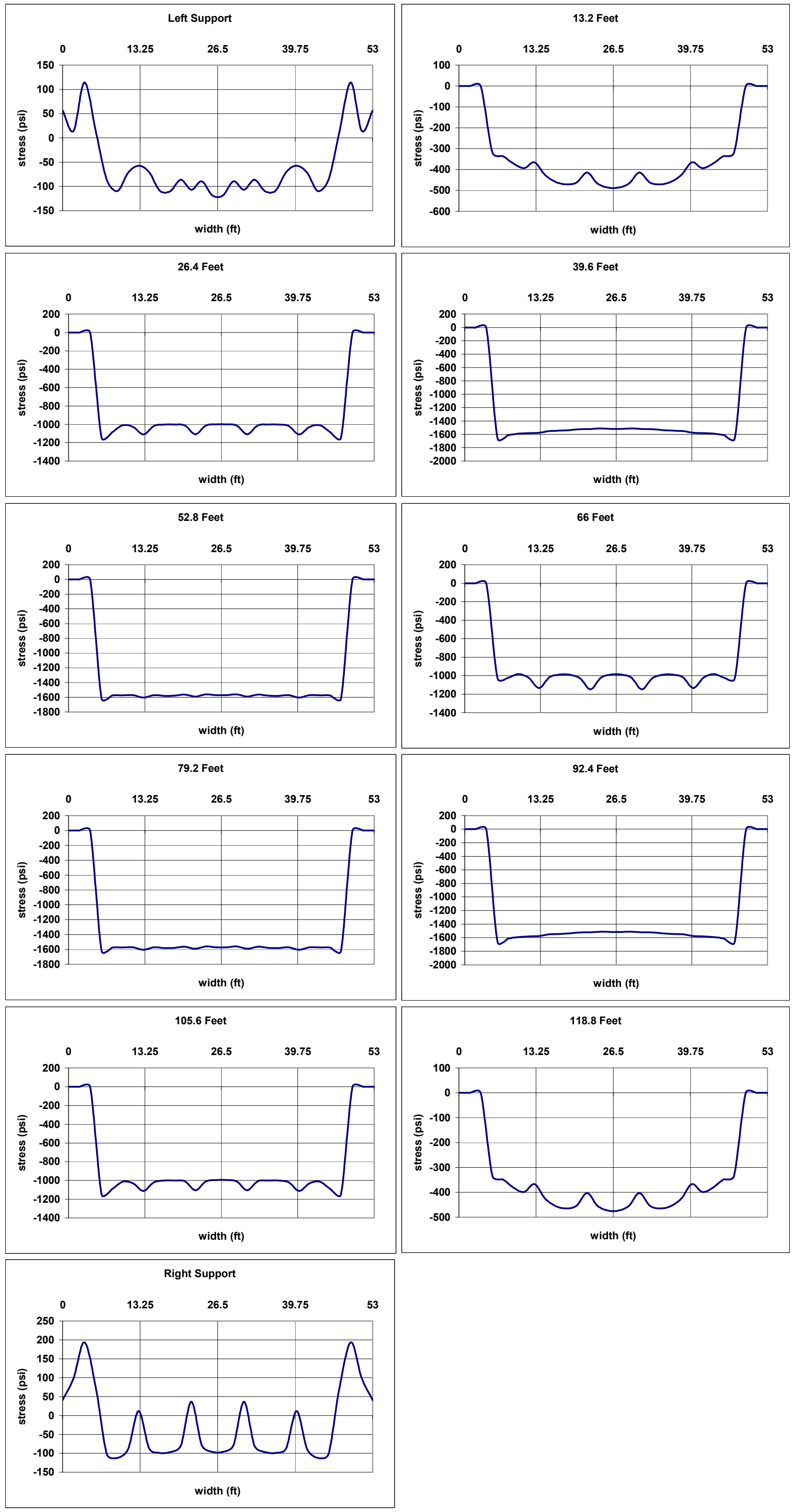

Figure C.50 Bridge G1697S, 22.63 feet from the Abutment, Bottom Fiber

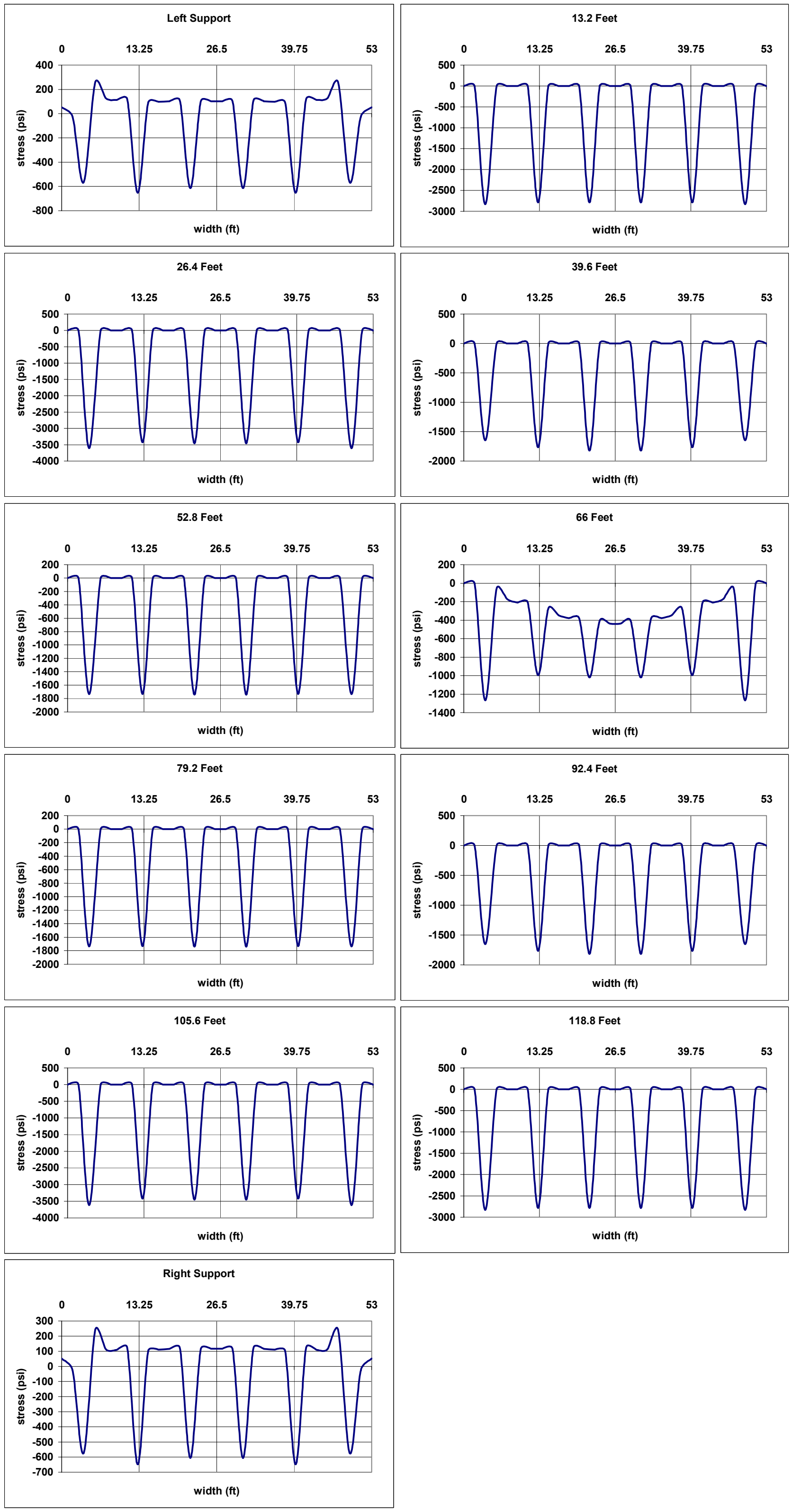

Figure C.51 Bridge G1697S, 28.29 feet from the Abutment, Top Fiber

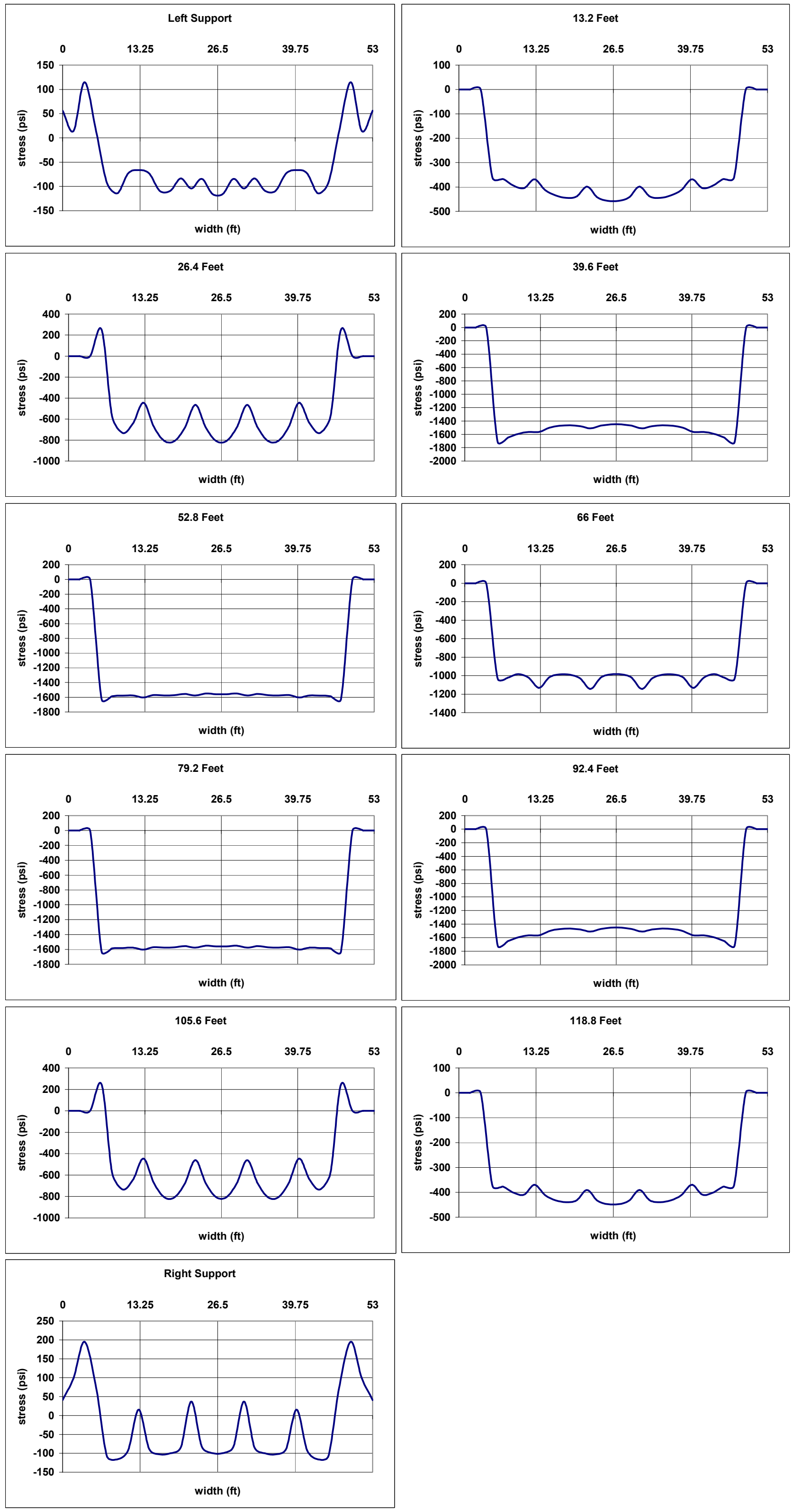

Figure C.52 Bridge G1697S, 28.29 feet from the Abutment, Bottom Fiber

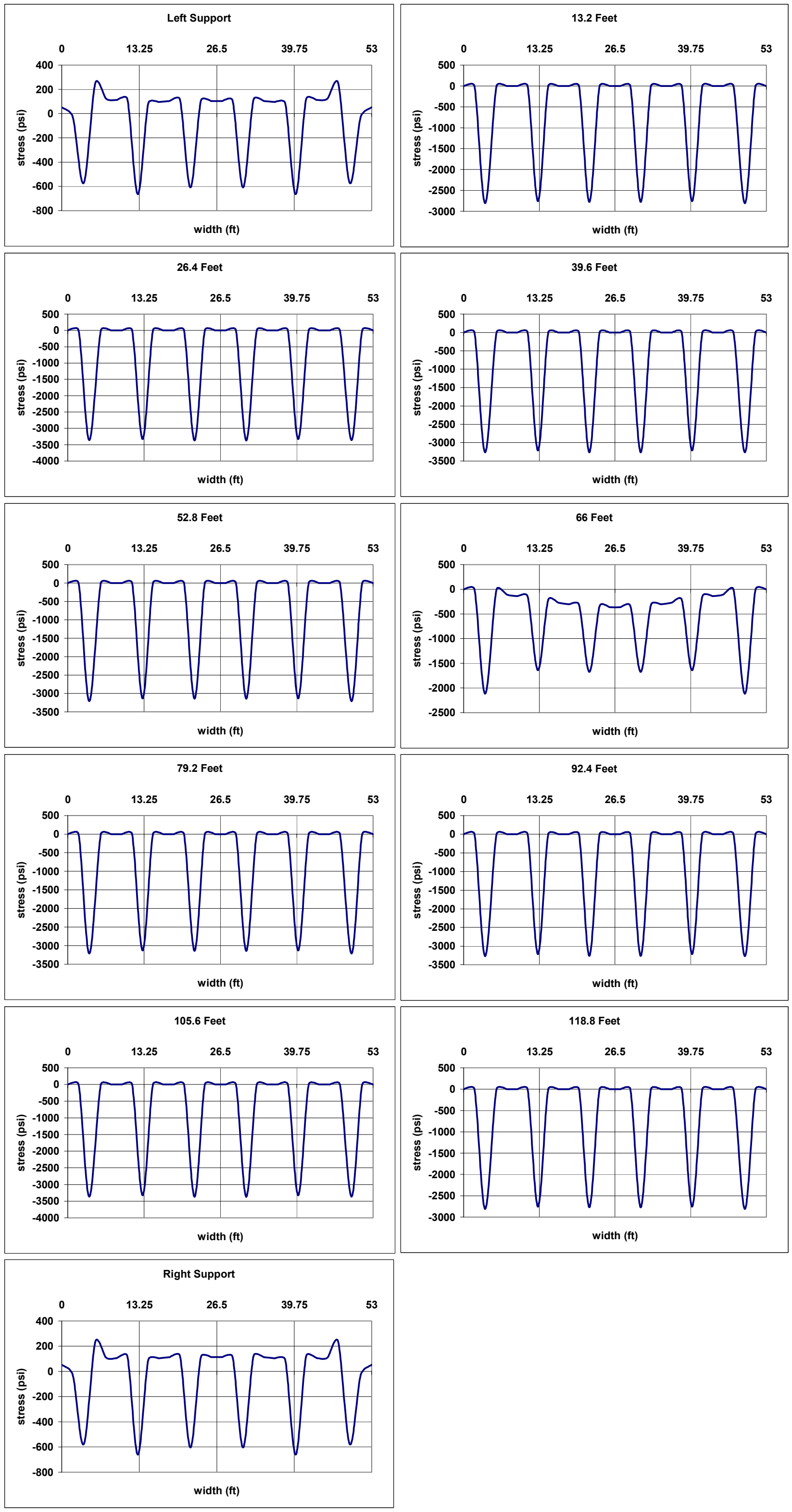

Figure C.53 Bridge G1697S, Stage 1, Top Fiber

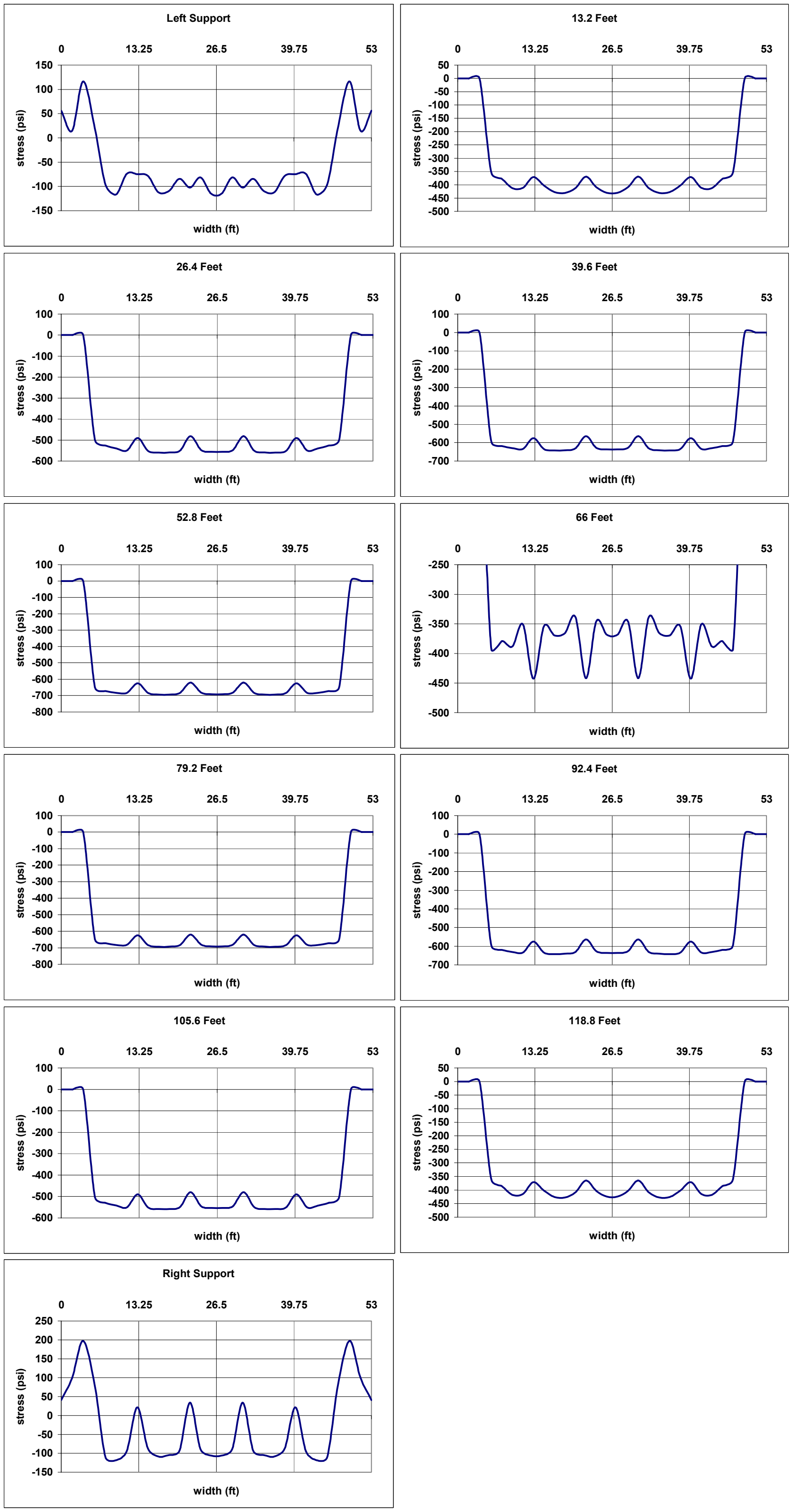

Figure C.54 Bridge G1697S, Stage 1, Bottom Fiber

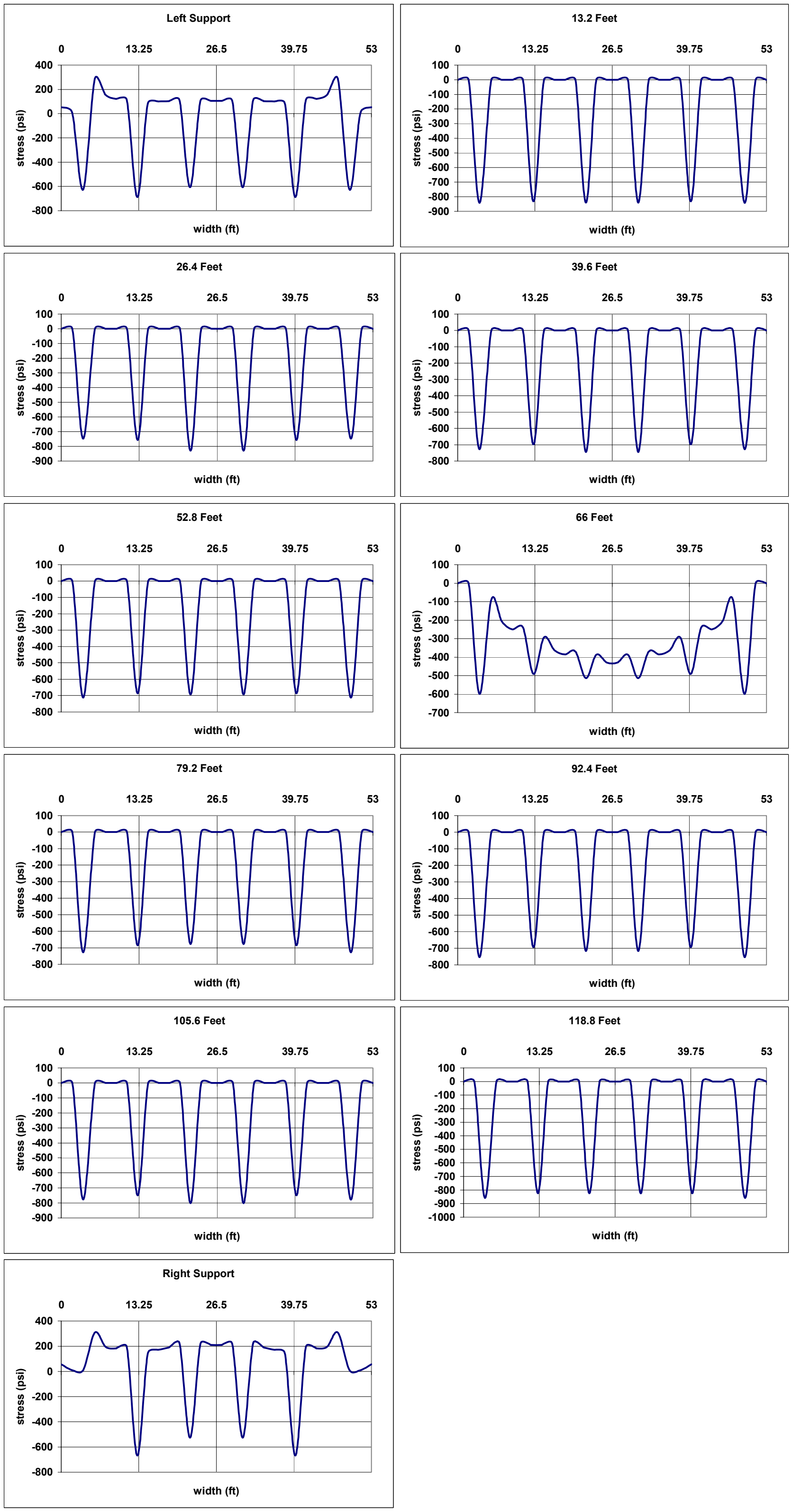

Figure C.55 Bridge G1697S, Stage 2, Top Fiber

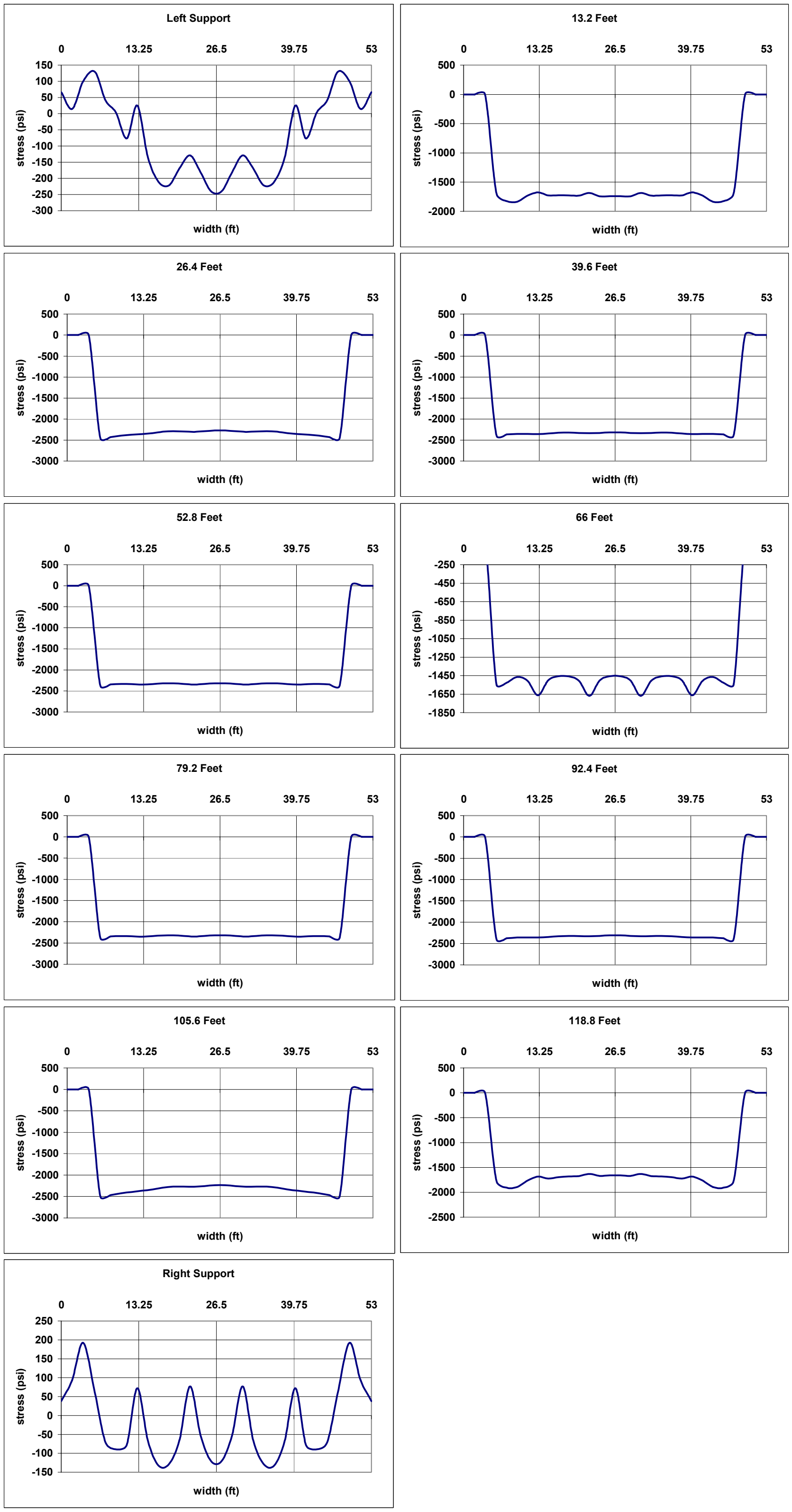

Figure C.56 Bridge G1697S, Stage 2, Bottom Fiber

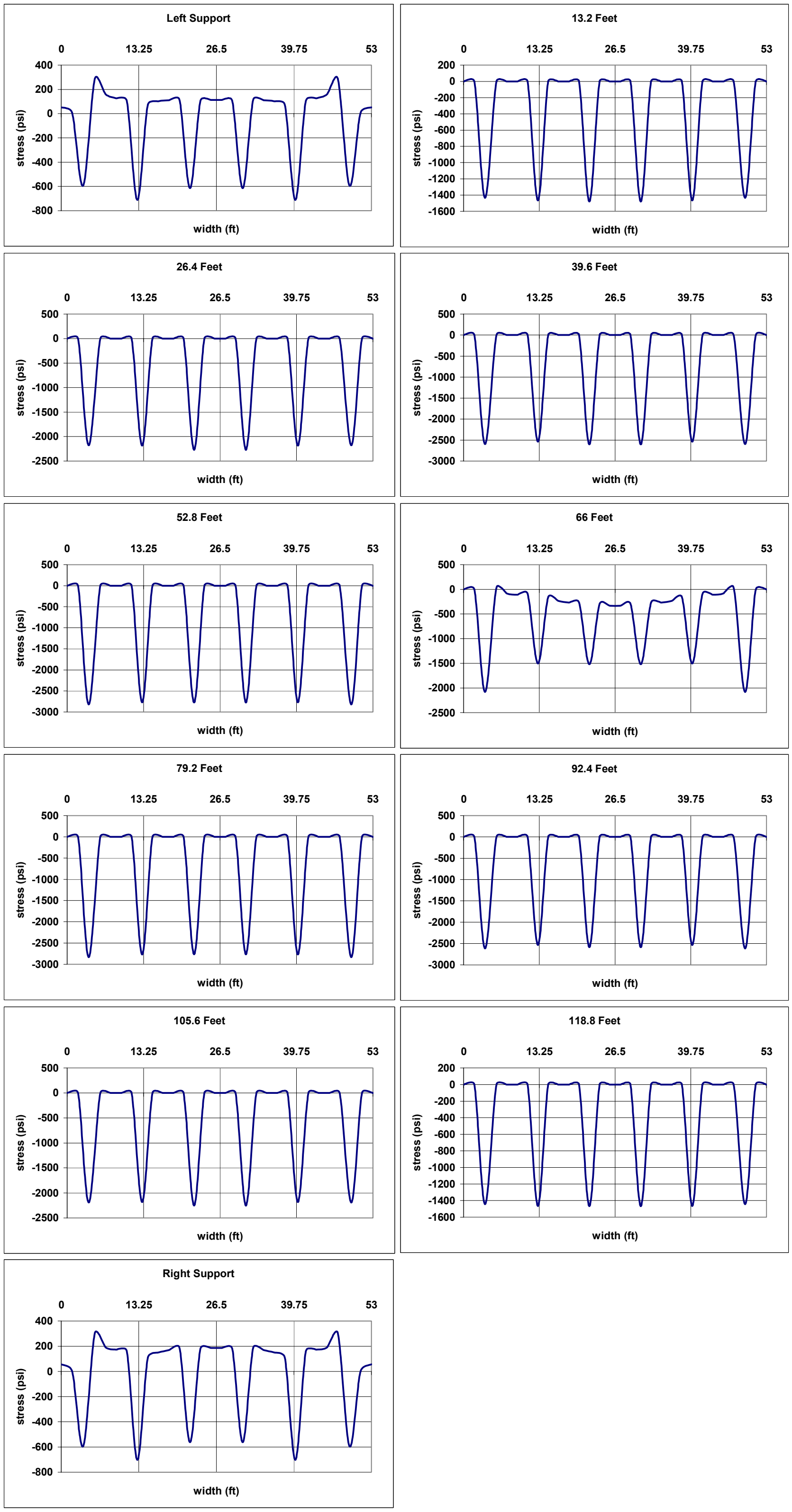

Figure C.57 Bridge G1697S, Stage 3, Top Fiber

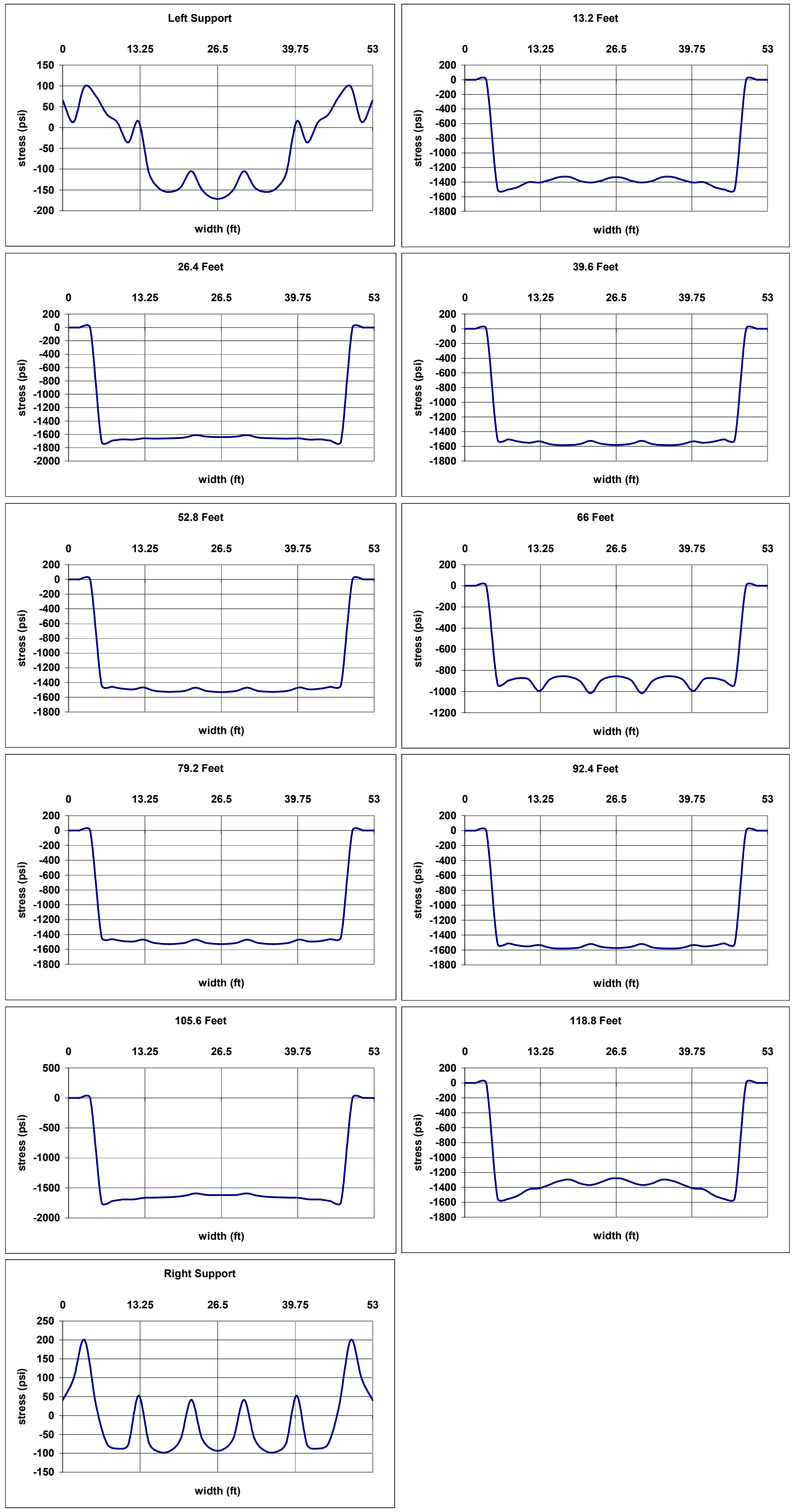

Figure C.58 Bridge G1697S, Stage 3, Bottom Fiber

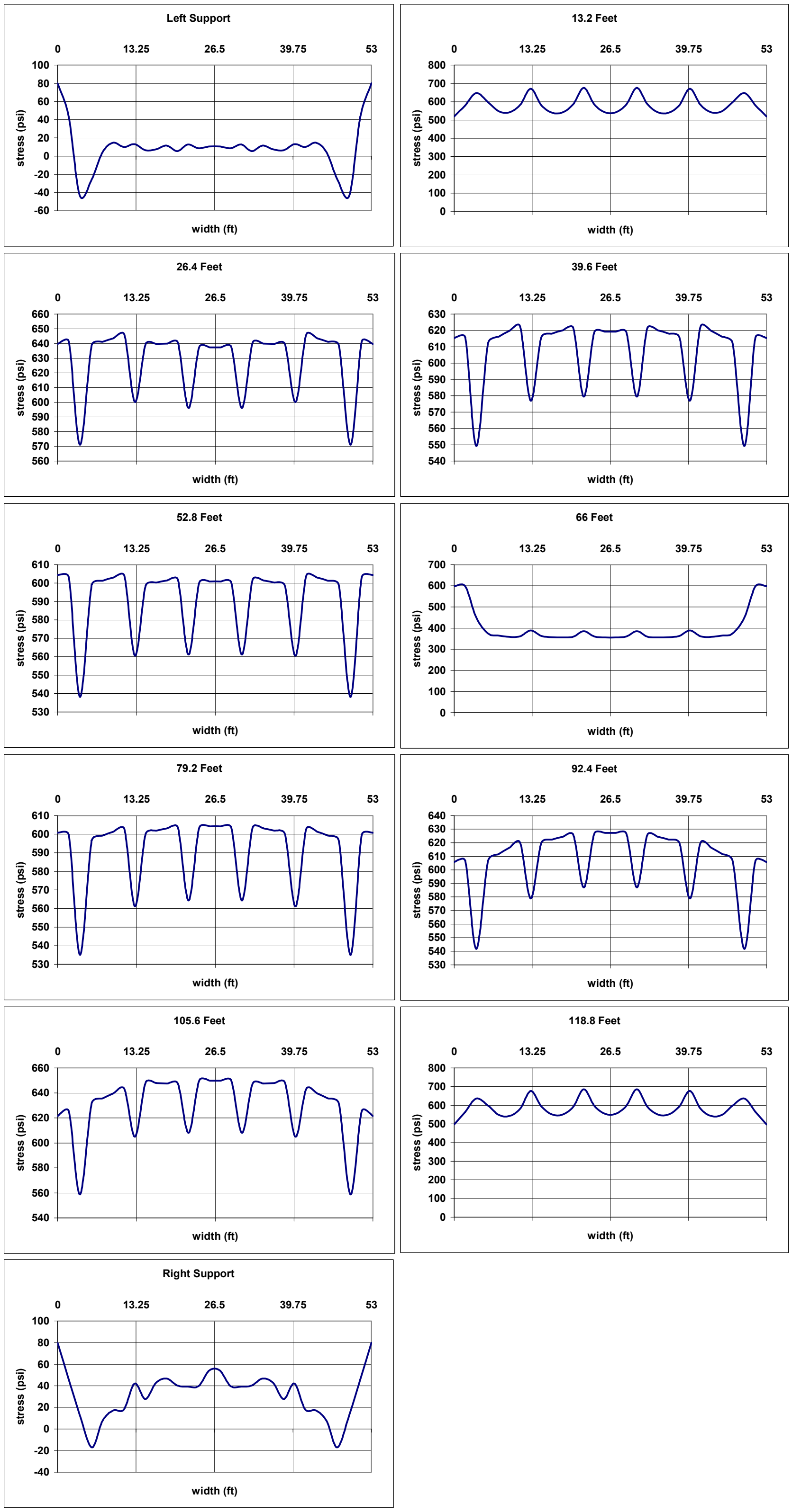

Figure C.59 Bridge G1697S, APS, Top Fiber

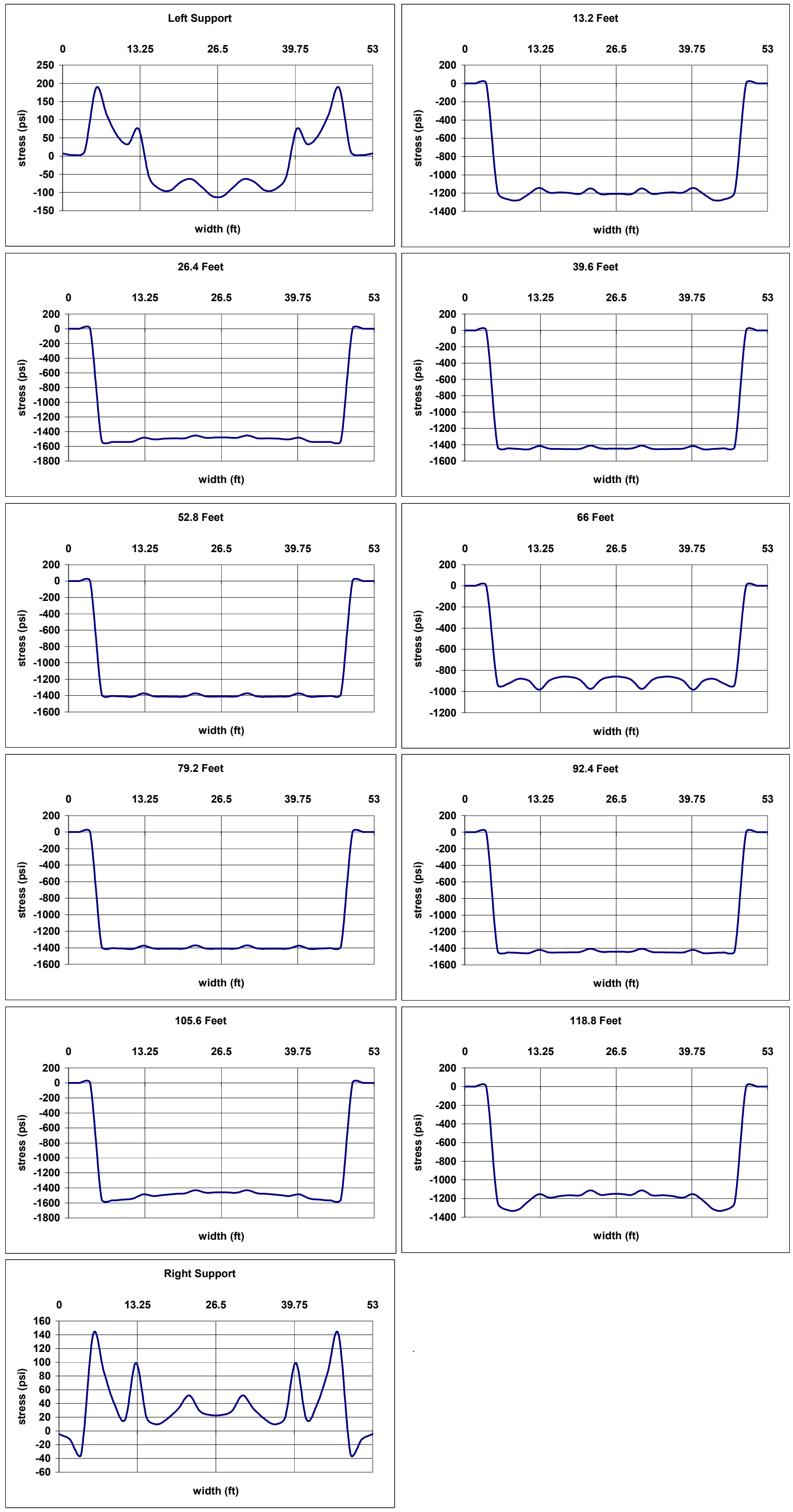

Figure C.60 Bridge G1697S, APS, Bottom Fiber

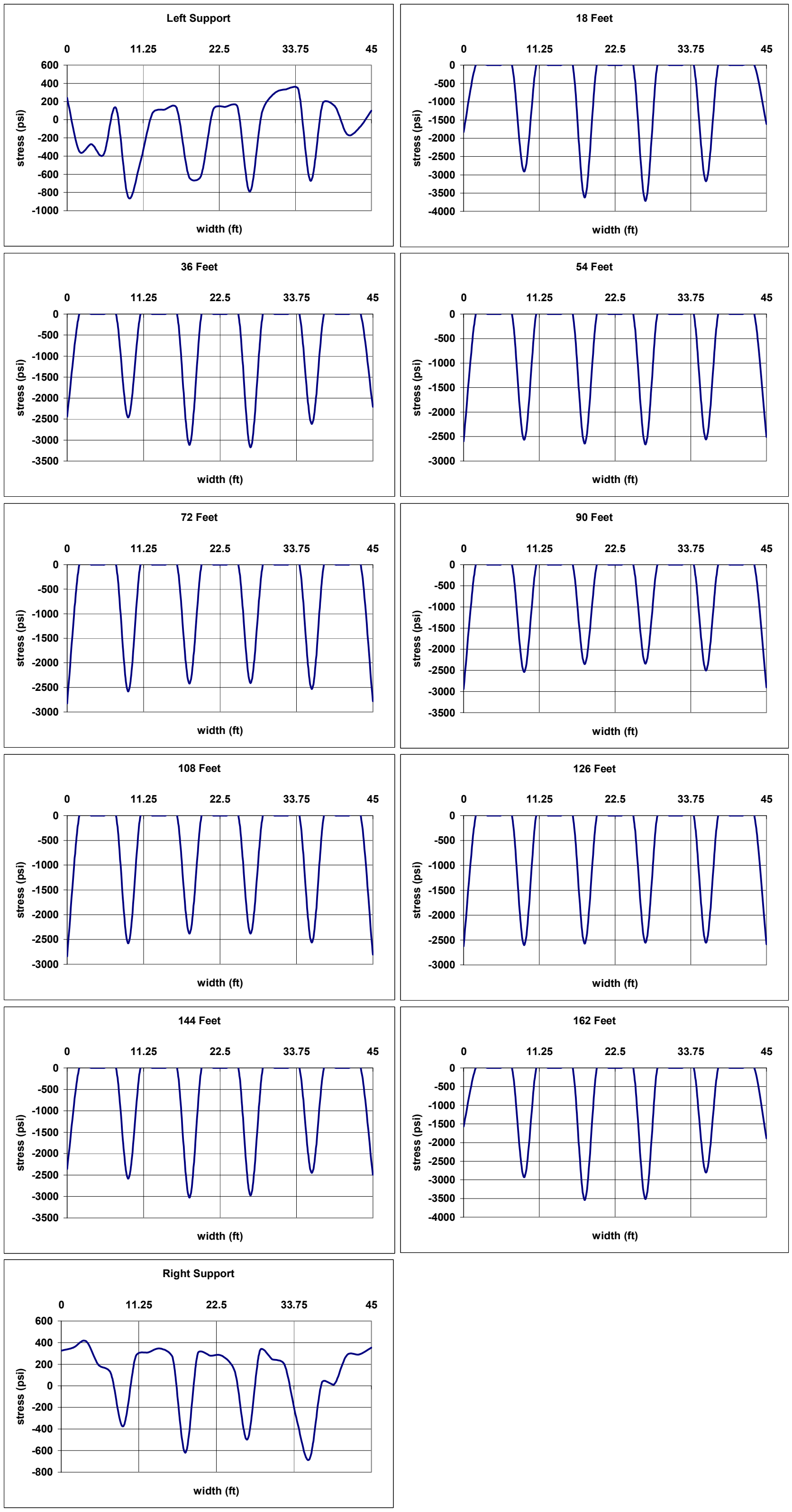

Figure C.61 Bridge I1301E, Stage 1, Top Fiber

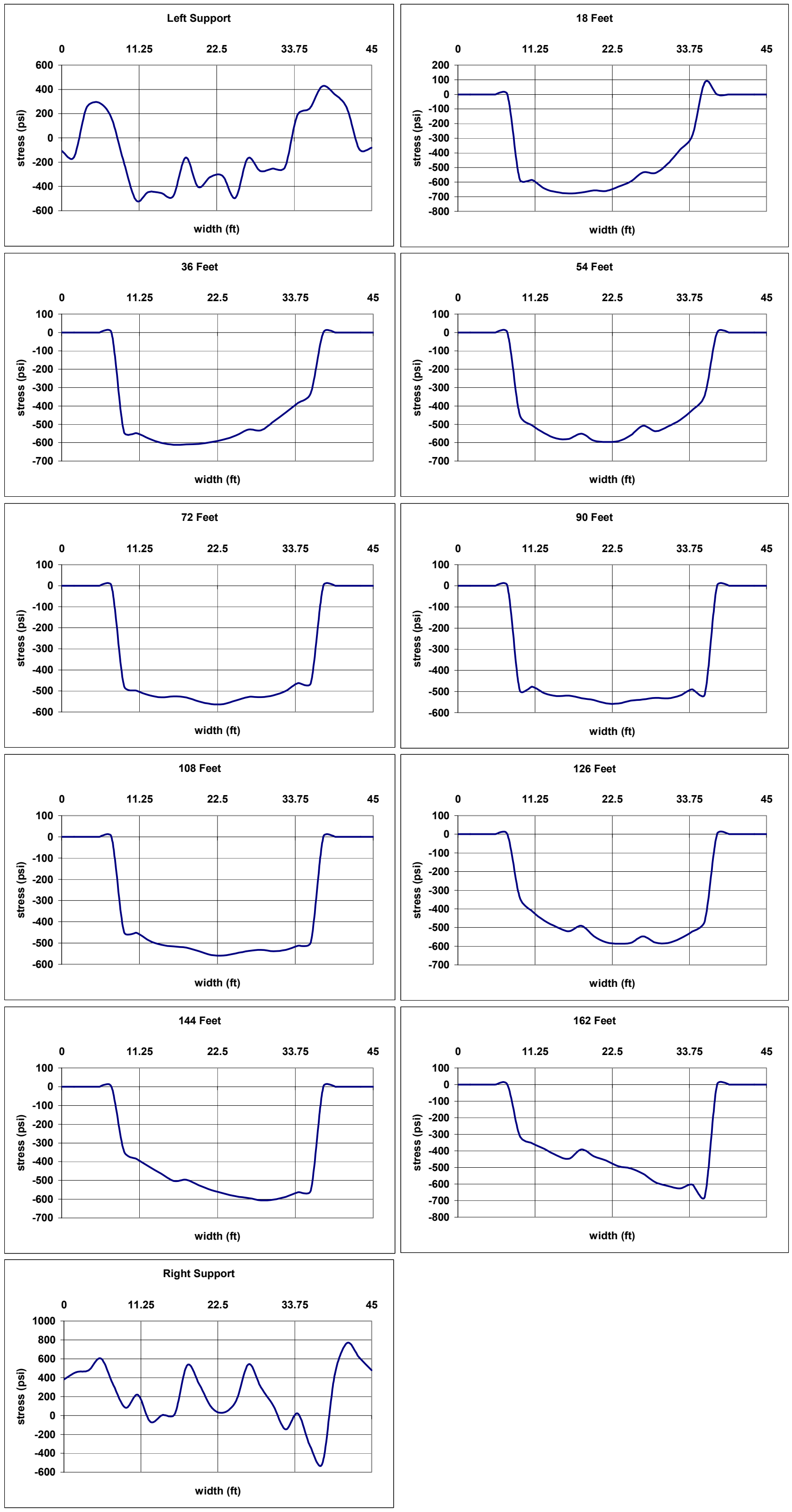

Figure C.62 Bridge I1301E, Stage 1, Bottom Fiber

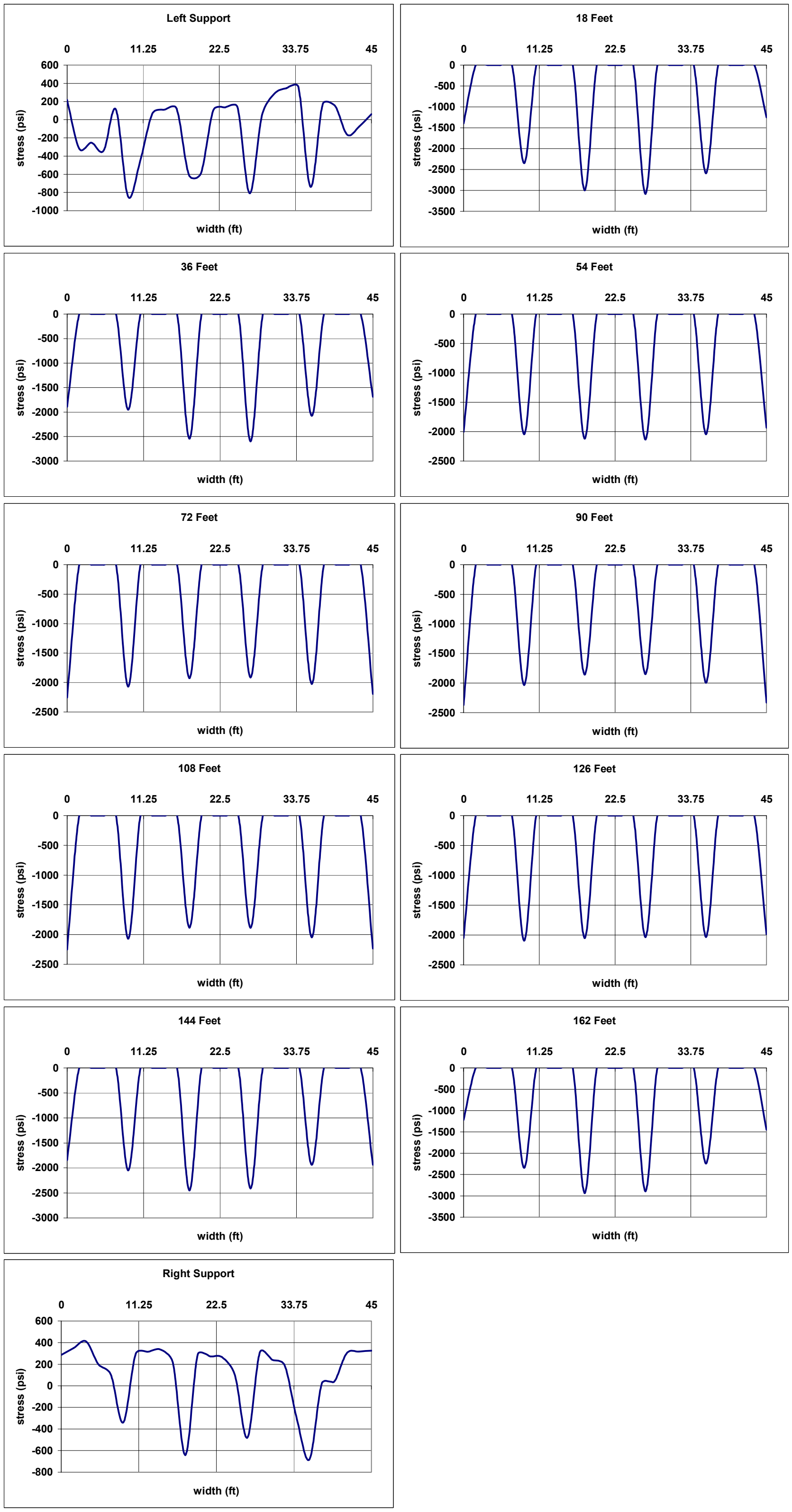

Figure C.63 Bridge I1301E, Stage 2, Top Fiber

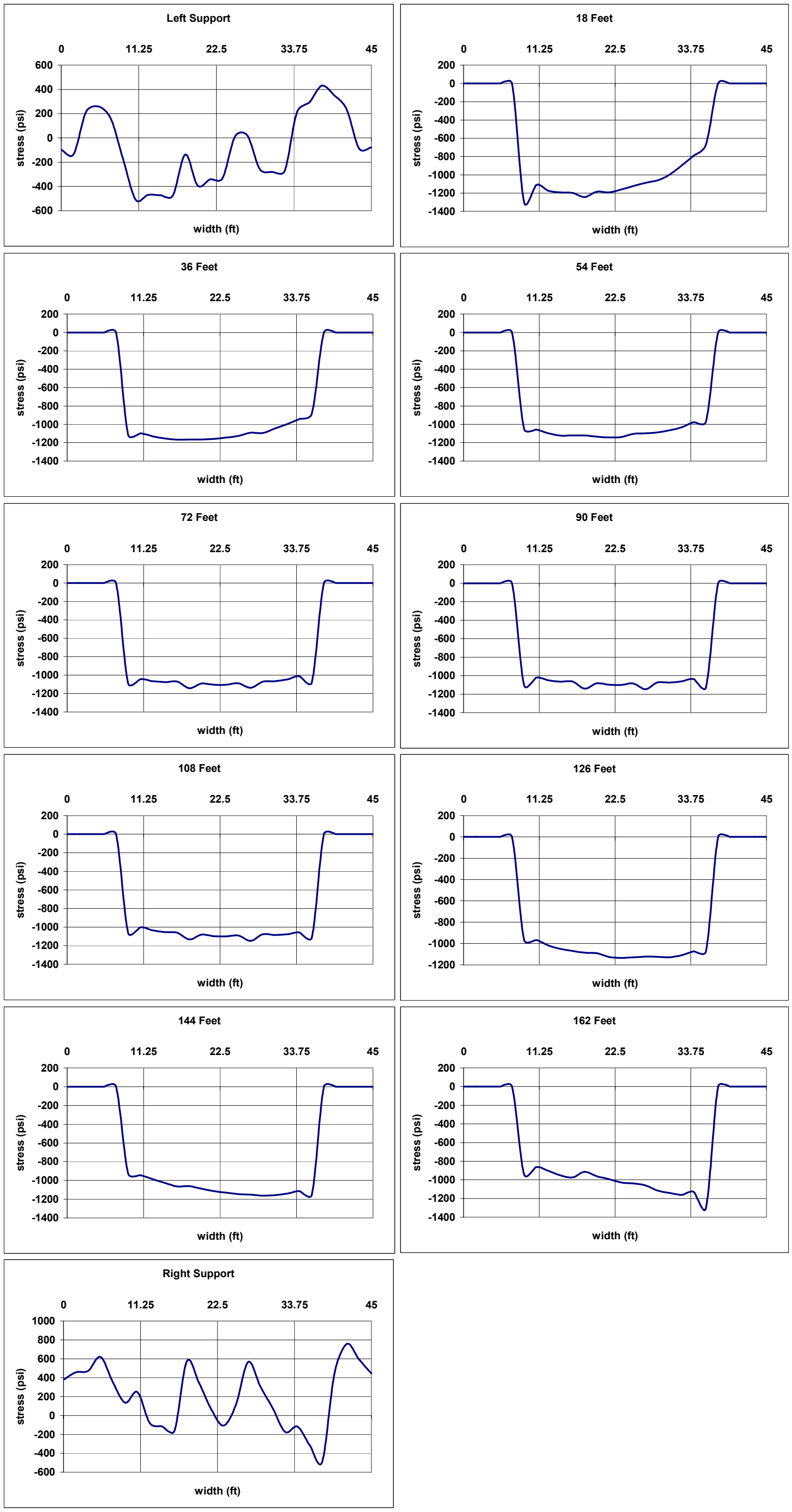

Figure C.64 Bridge I1301E, Stage 2, Bottom Fiber

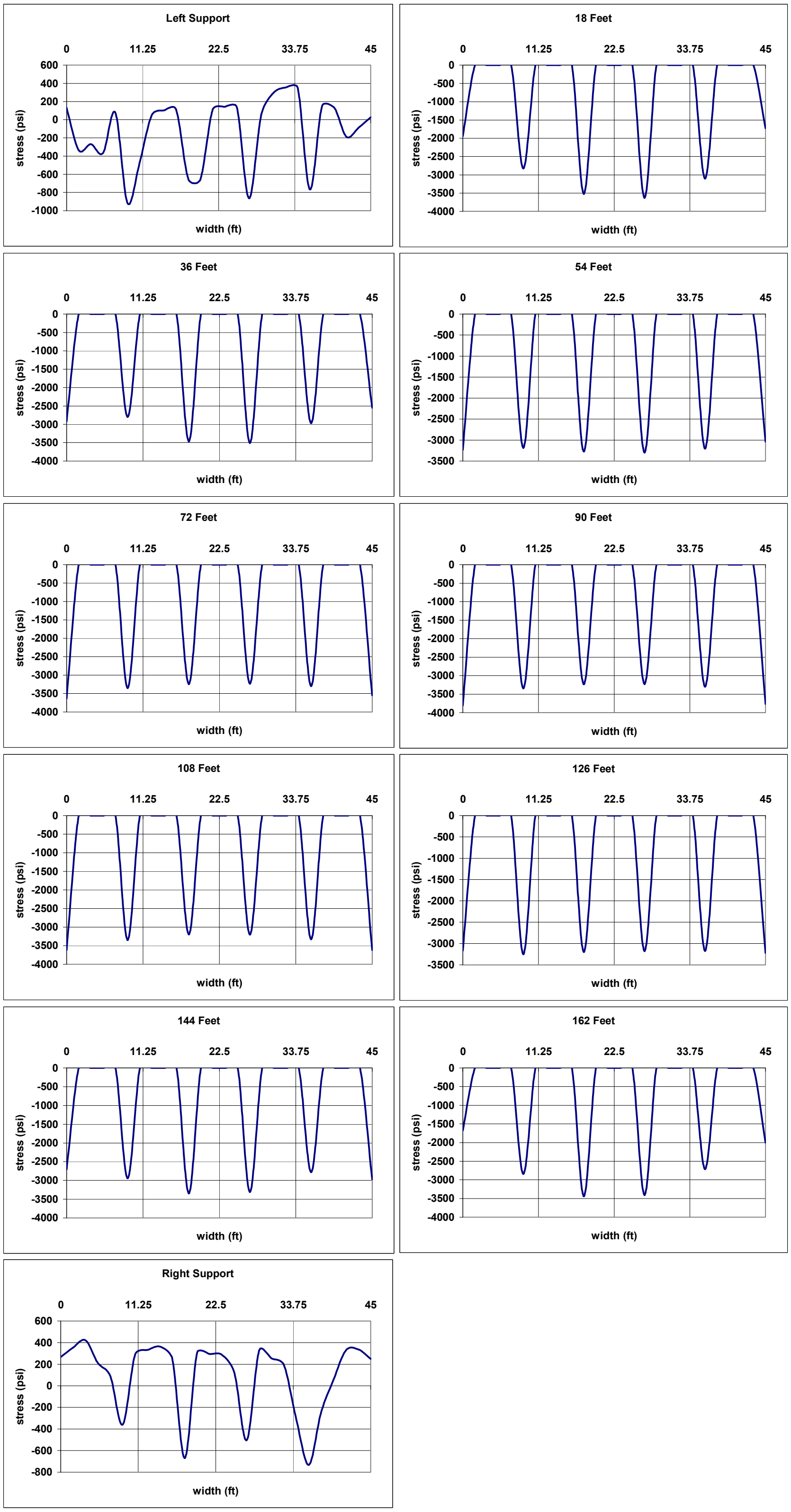

Figure C.65 Bridge I1301E, Stage 3, Top Fiber

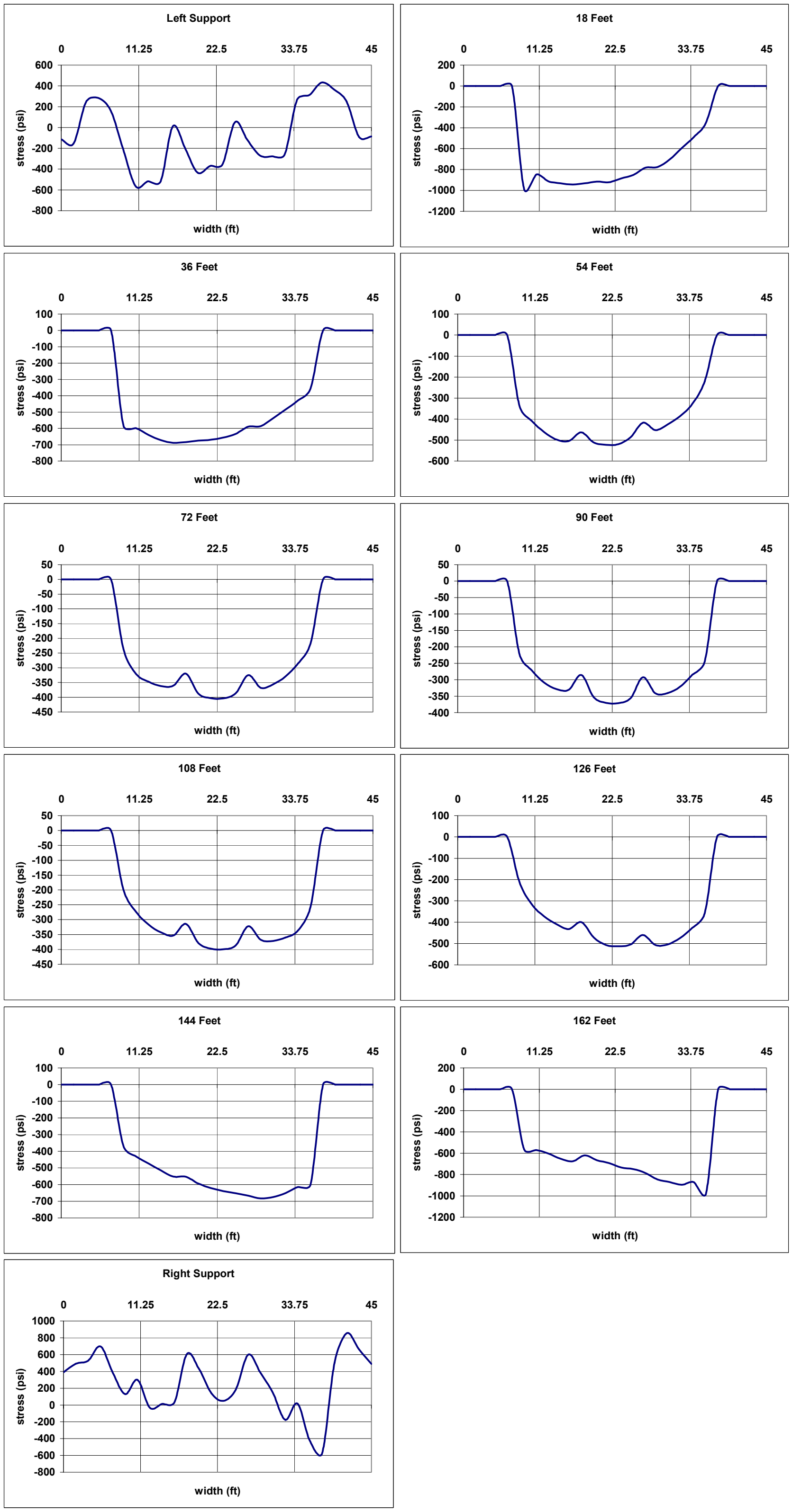

Figure C.66 Bridge I1301E, Stage 3, Bottom Fiber

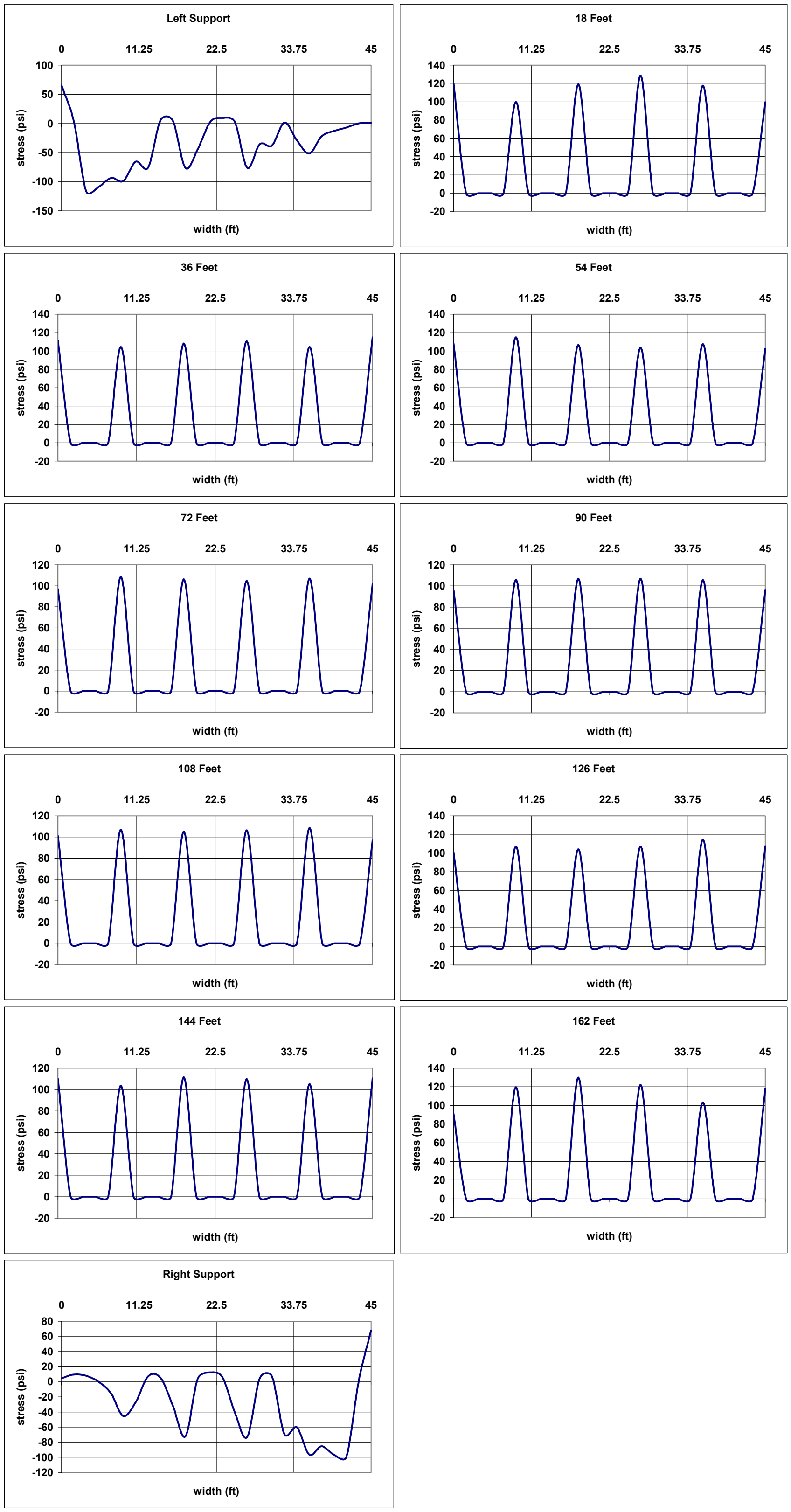

Figure C.67 Bridge I1301E, APS, Top Fiber

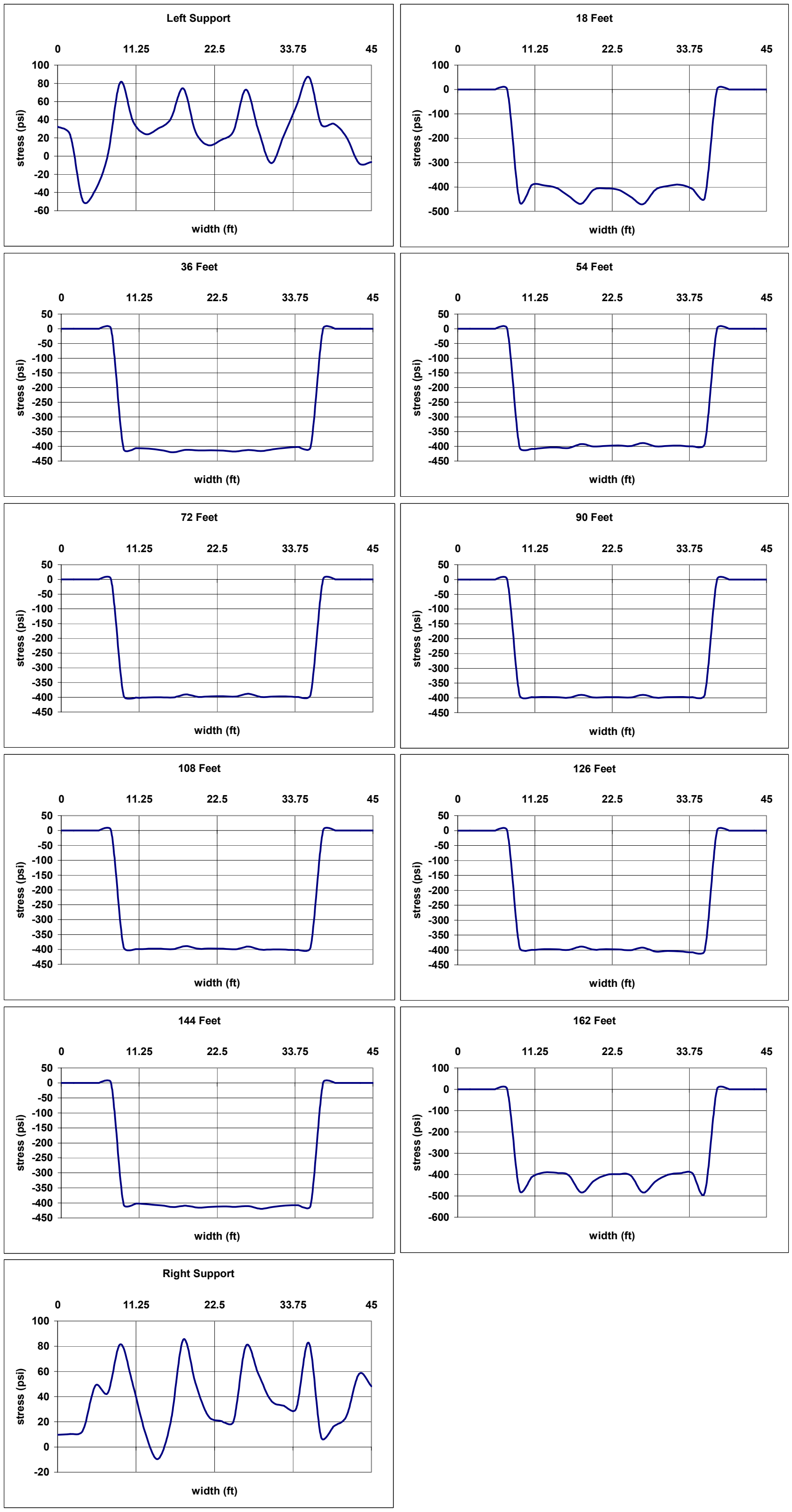

Figure C.68 Bridge I1301E, APS, Bottom Fiber

Appendix D

Figures Related to Chapter 4

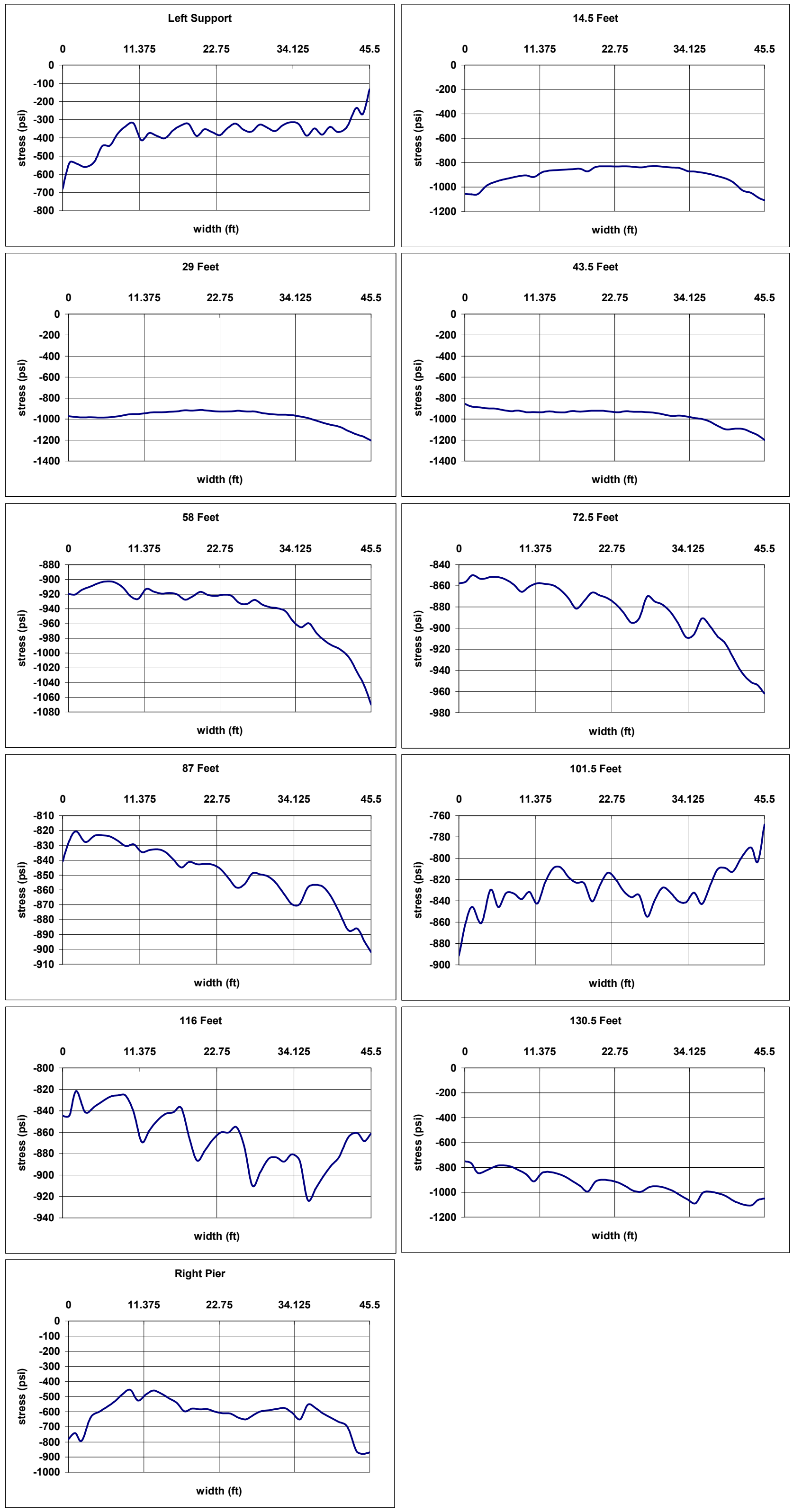

Figure D.1 Bridge I871E, Span 1, Stage 1, Top Fiber

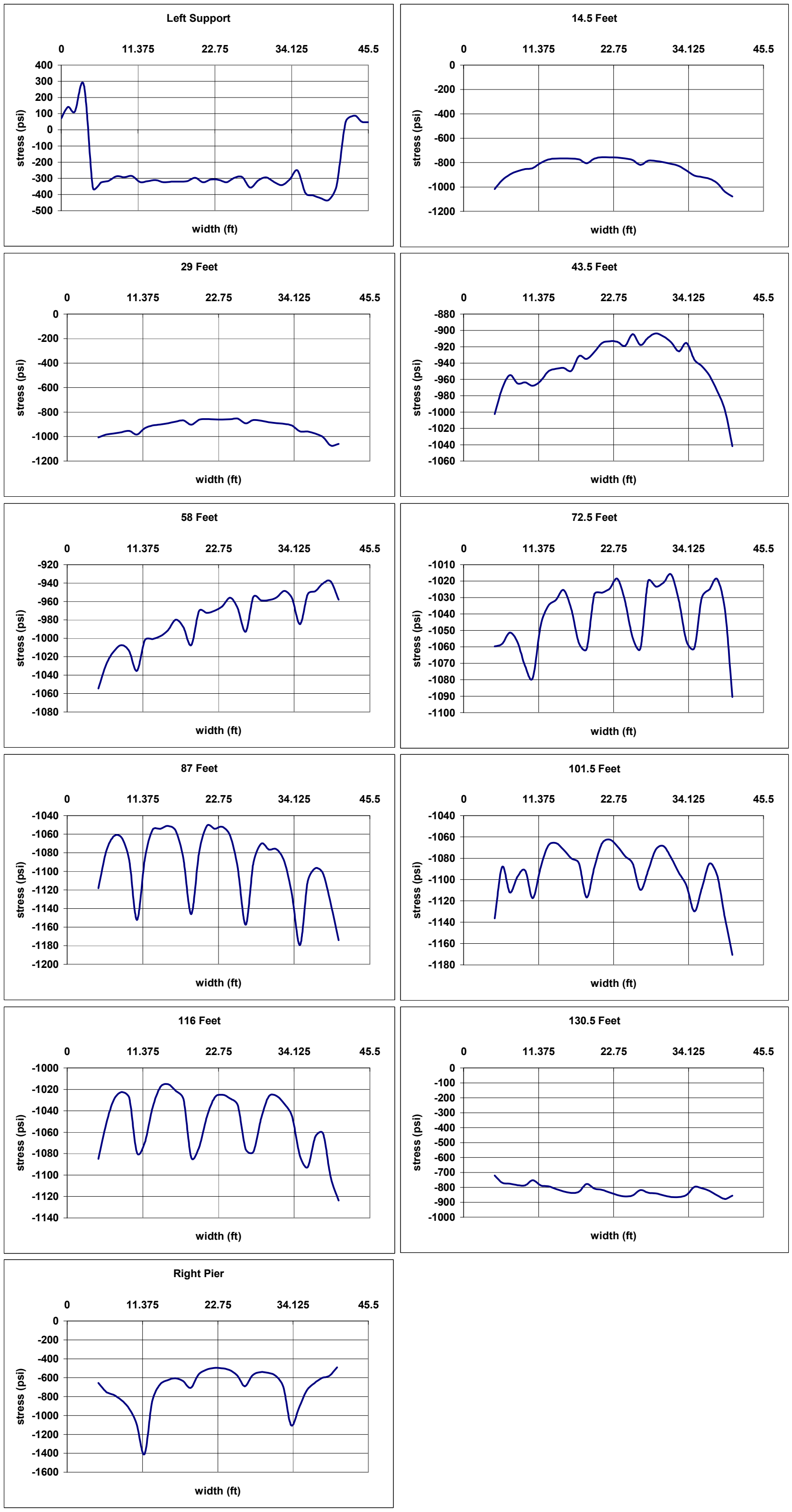

Figure D.2 Bridge I871E, Span 1, Stage 1, Bottom Fiber

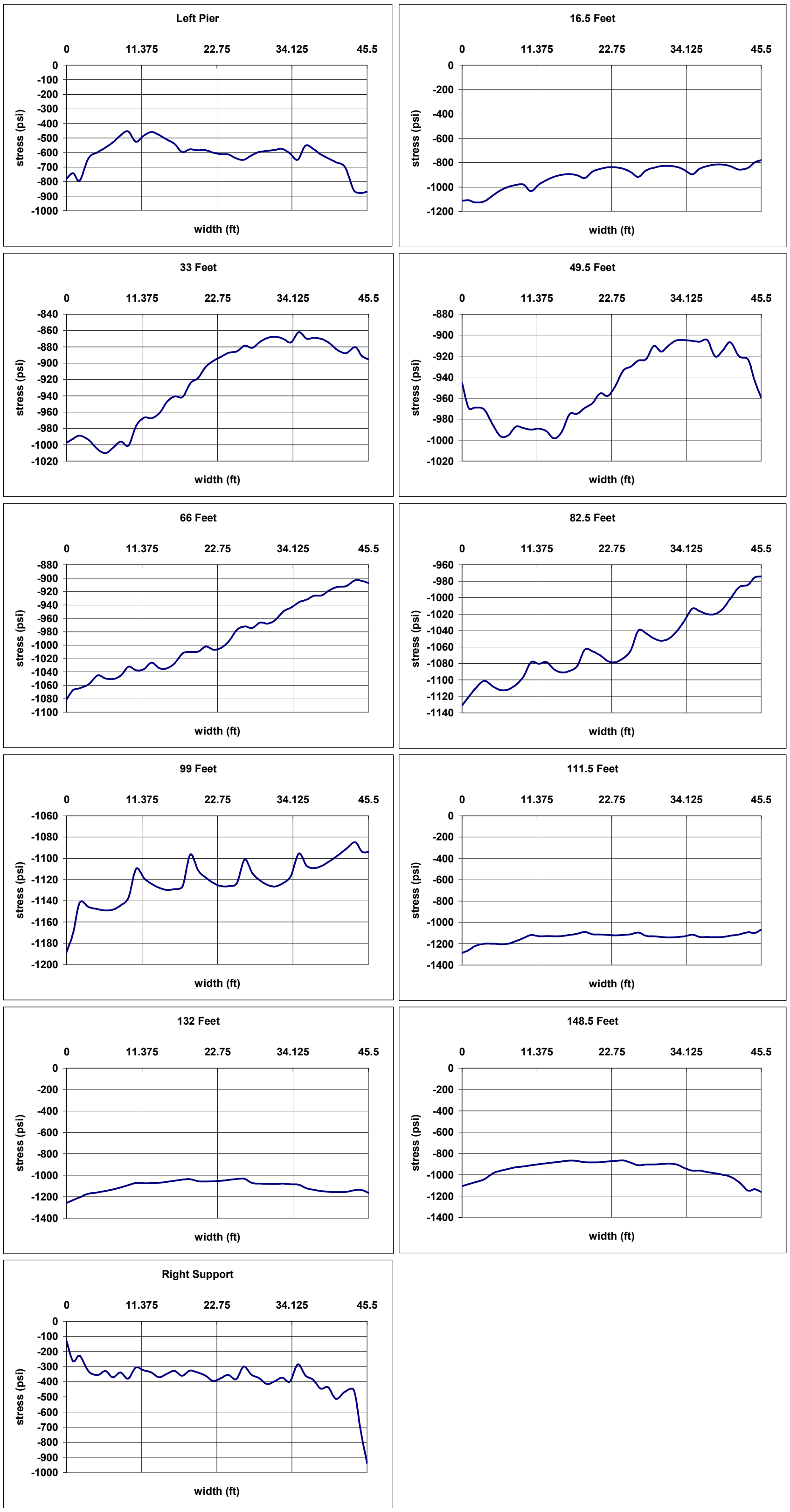

Figure D.3 Bridge I871E, Span 2, Stage 1, Top Fiber

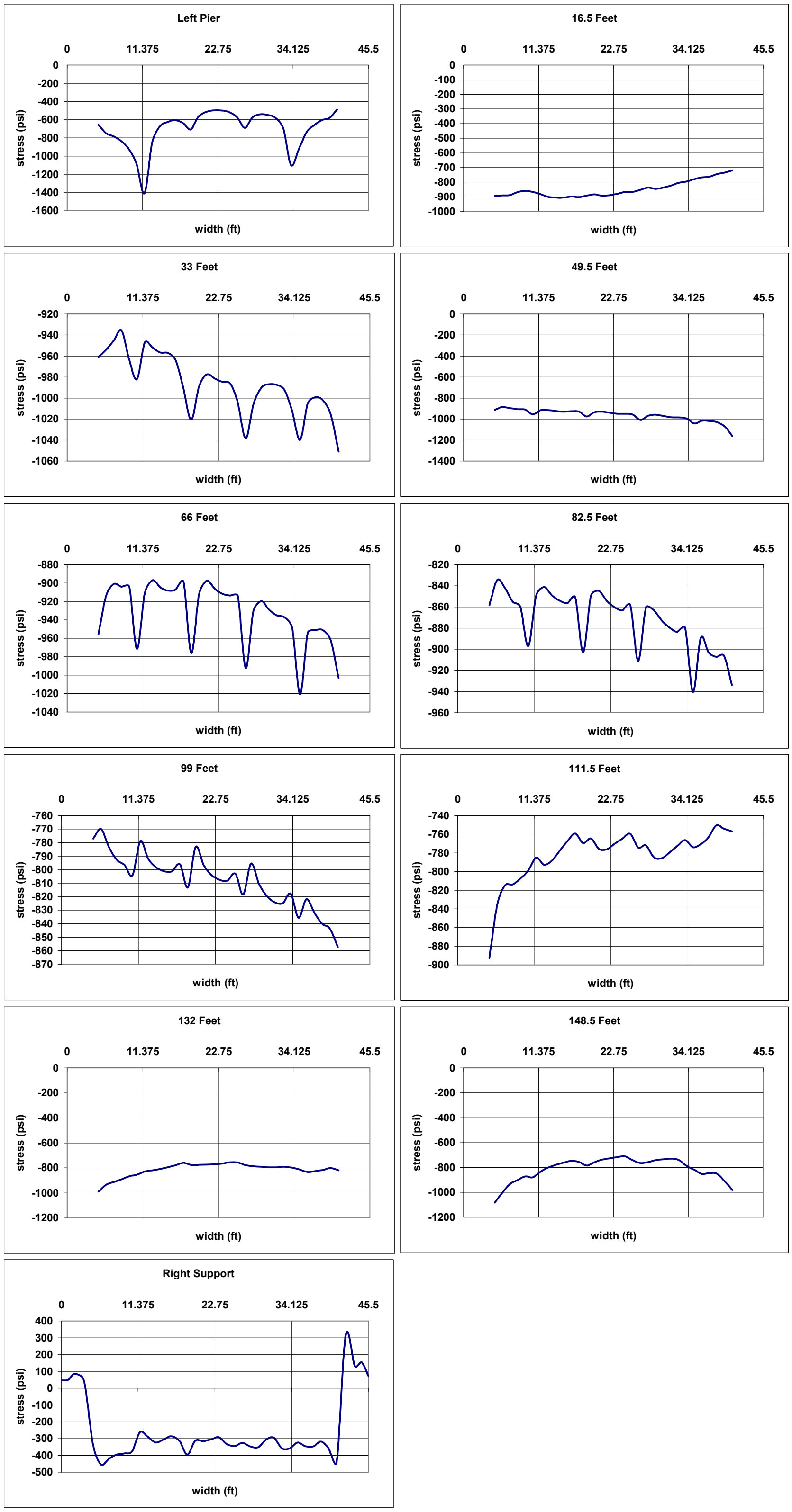

Figure D.4 Bridge I871E, Span 2, Stage 1, Bottom Fiber

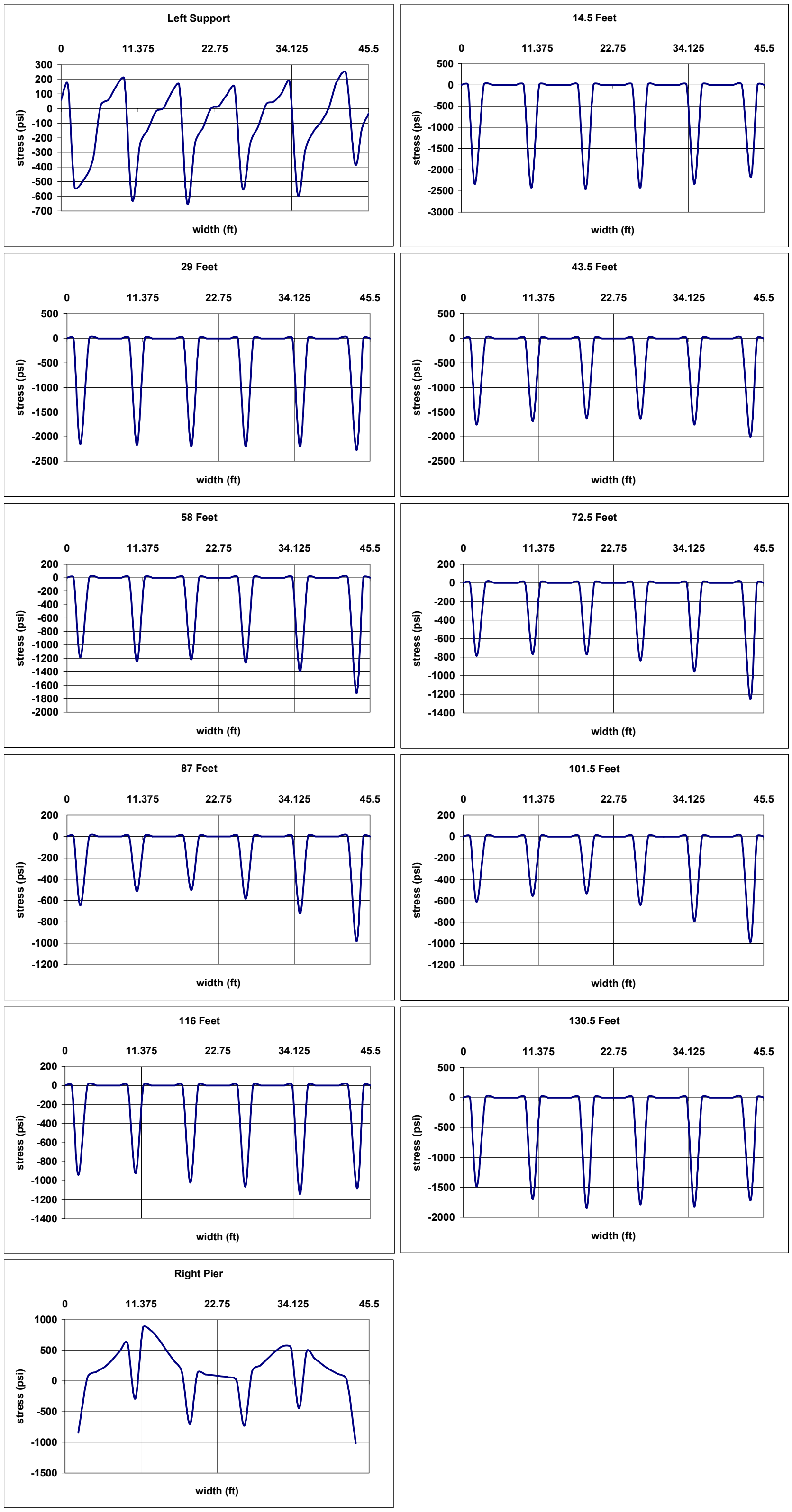

Figure D.5 Bridge I871E, Span 1, Stage 2, Top Fiber

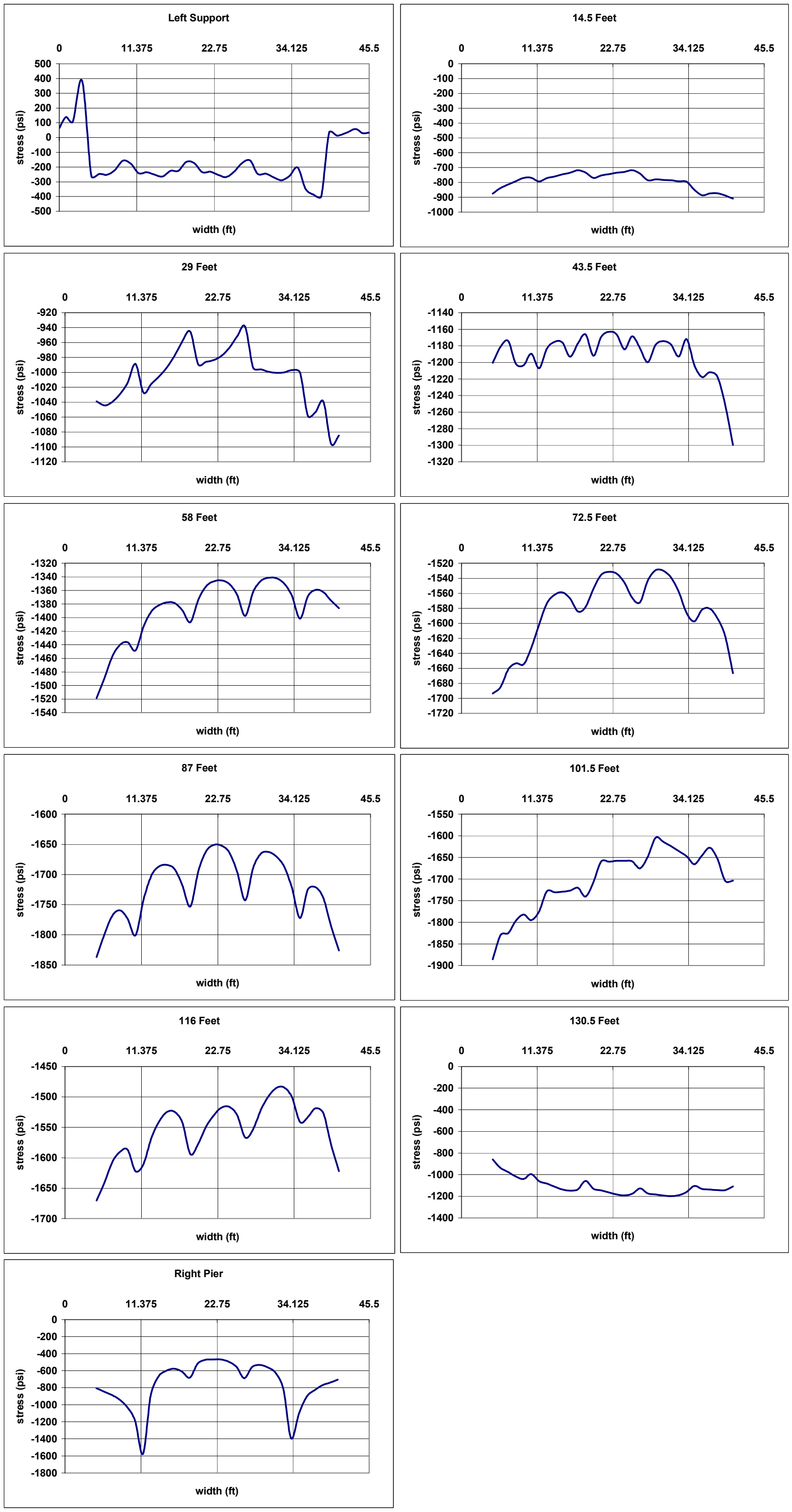

Figure D.6 Bridge I871E, Span 1, Stage 2, Bottom Fiber

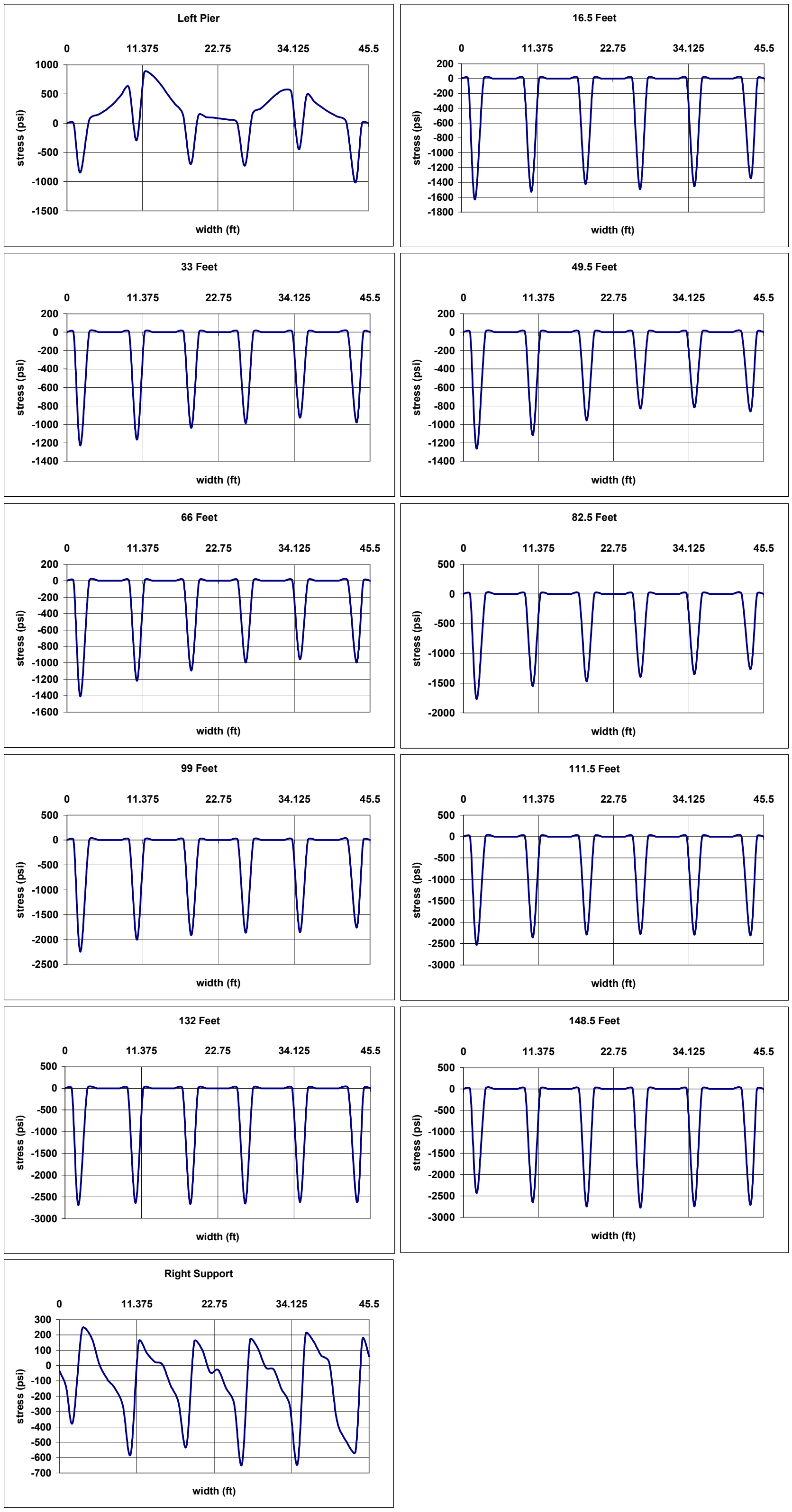

Figure D.7 Bridge I871E, Span 2, Stage 2, Top Fiber

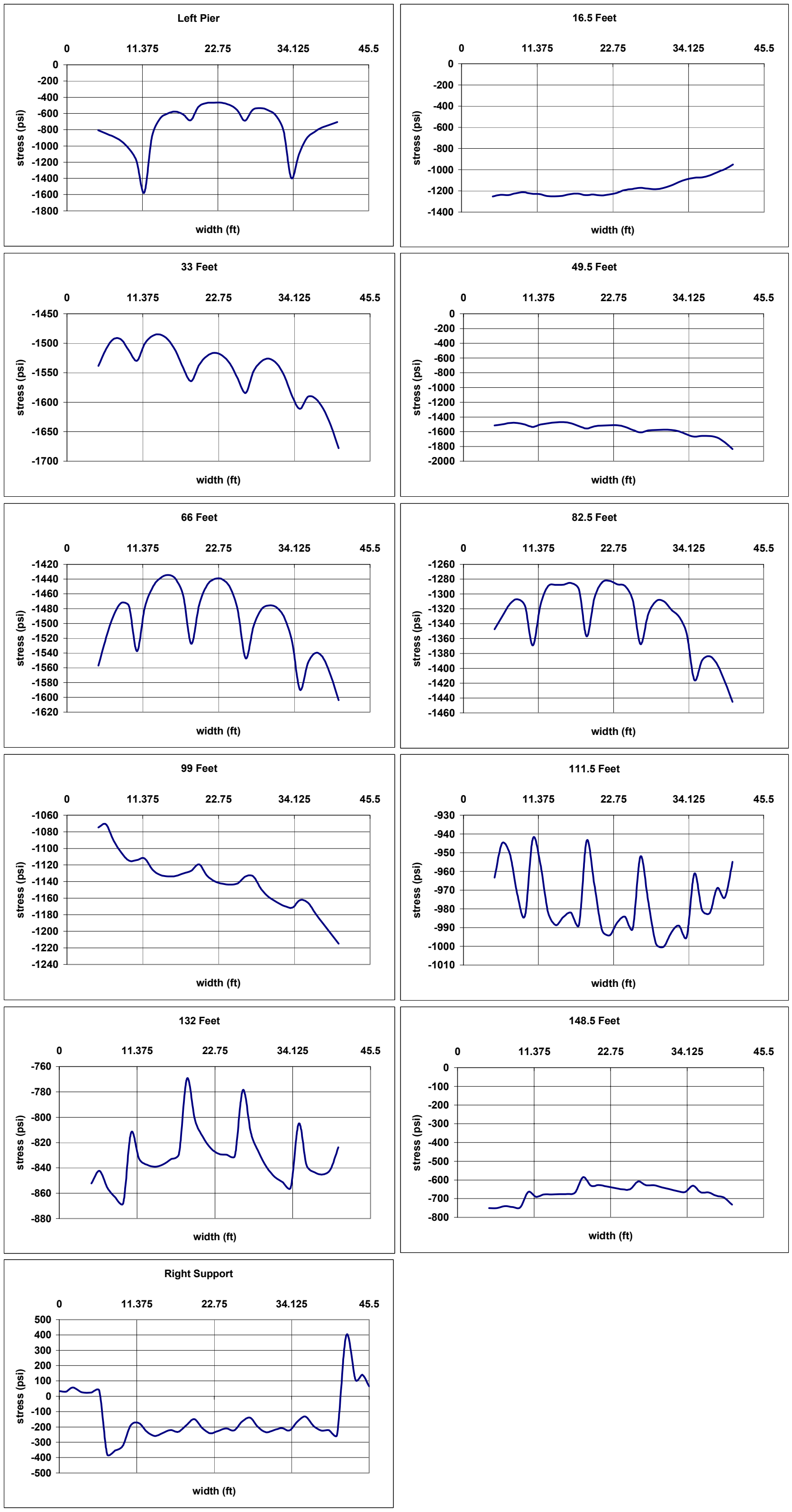

Figure D.8 Bridge I871E, Span 2, Stage 2, Bottom Fiber

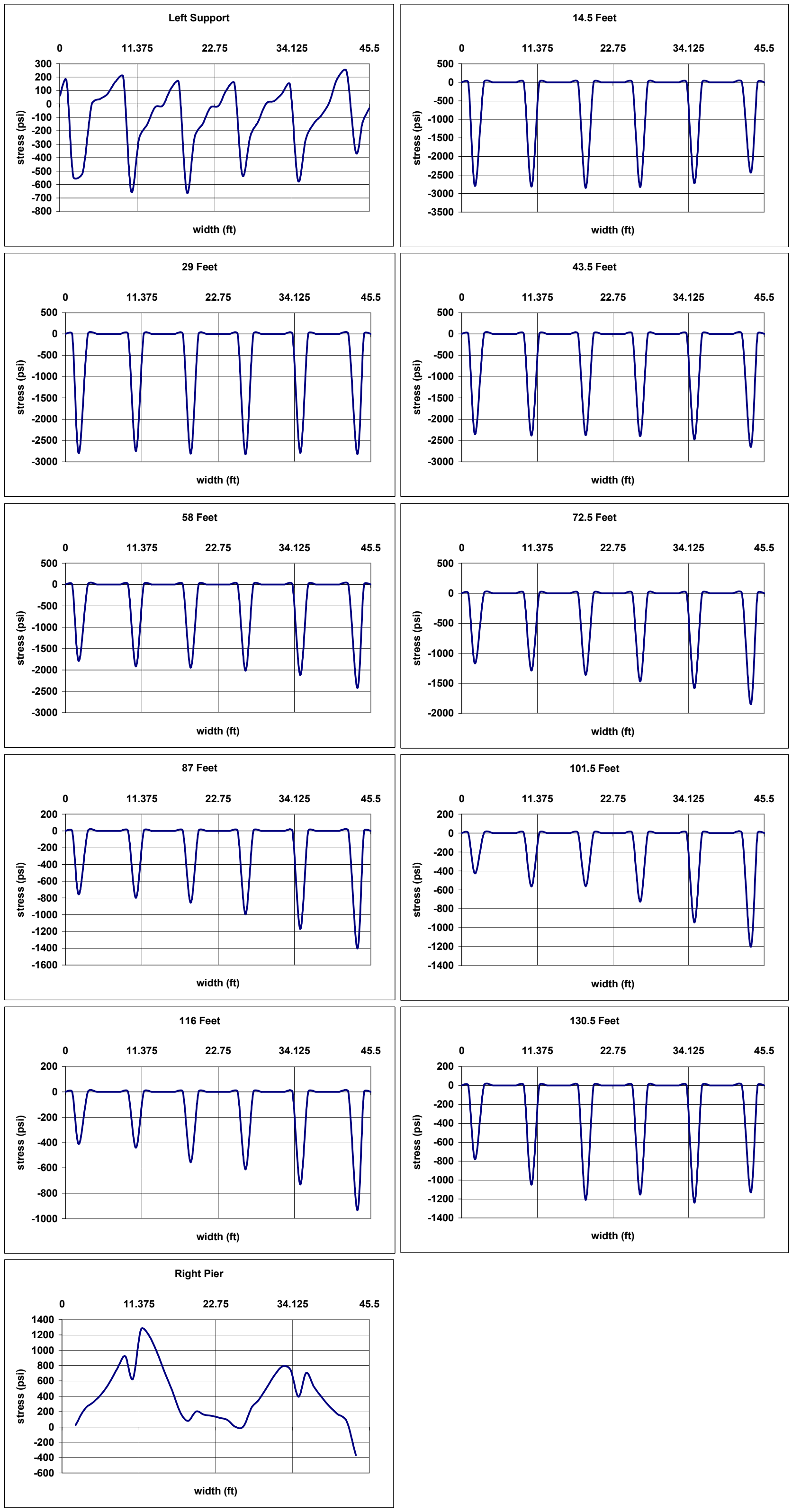

Figure D.9 Bridge I871E, Span 1, Stage 3, Top Fiber

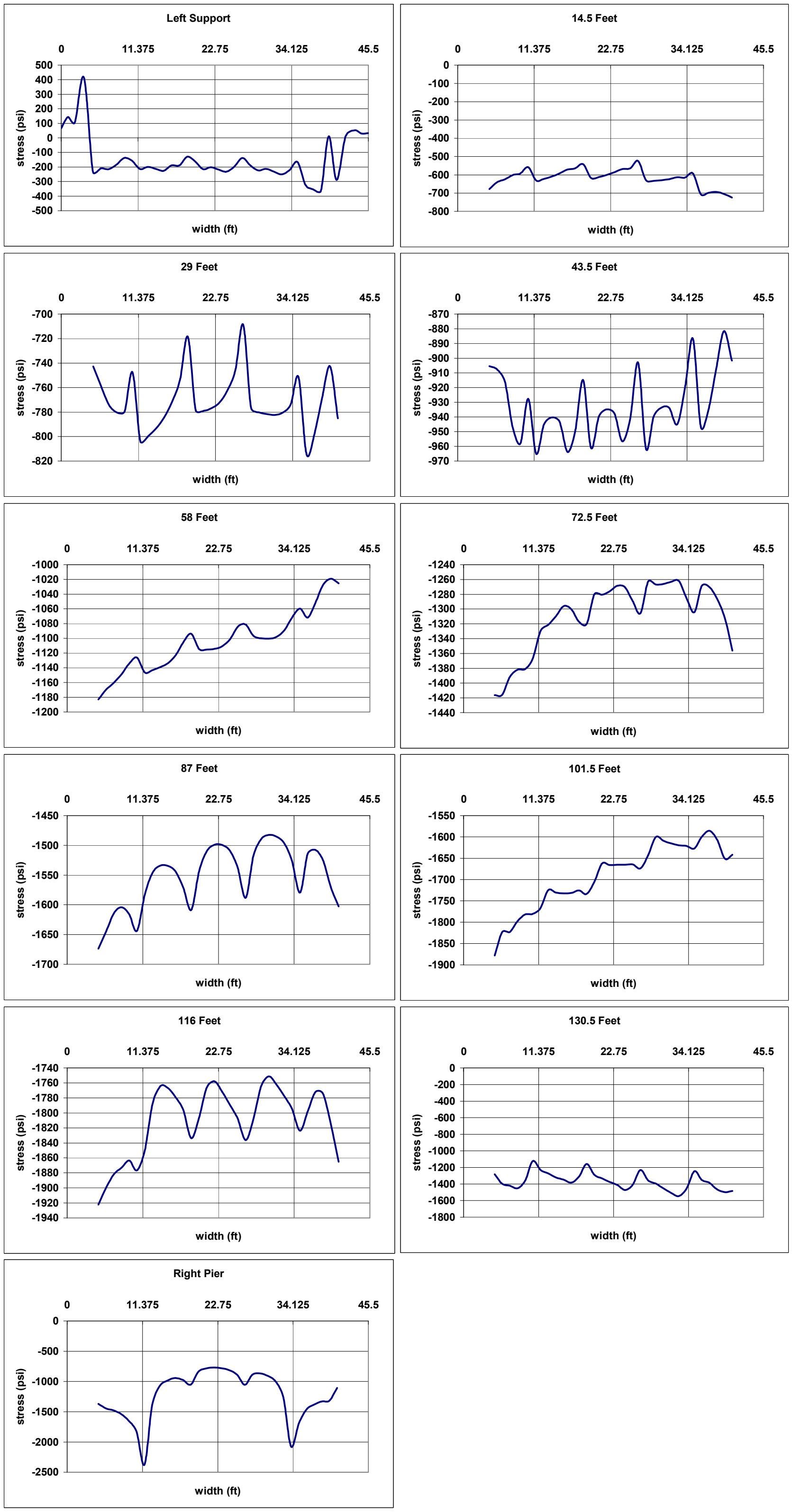

Figure D.10 Bridge I871E, Span 1, Stage 3, Bottom Fiber

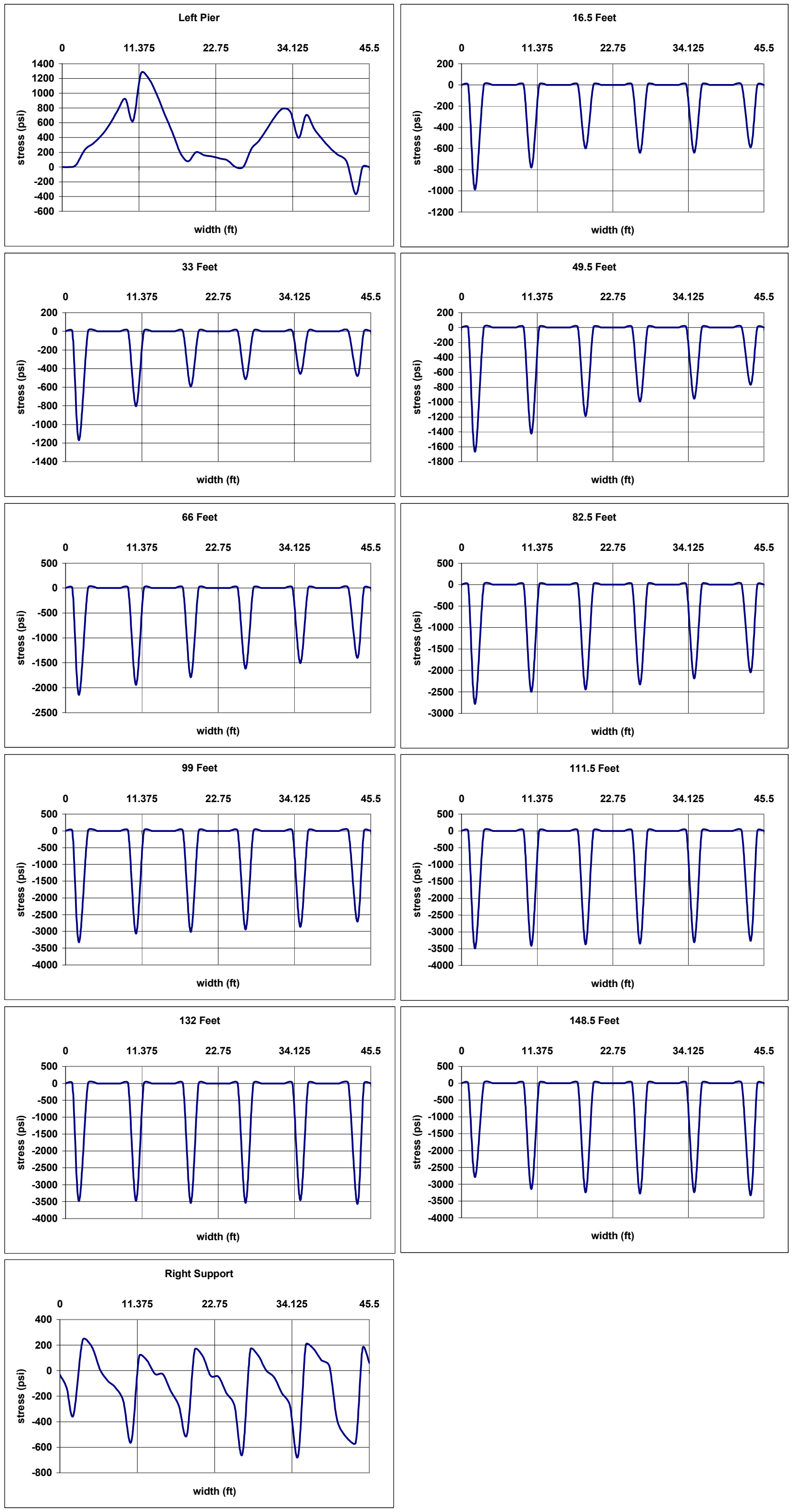

Figure D.11 Bridge I871E, Span 2, Stage 3, Top Fiber

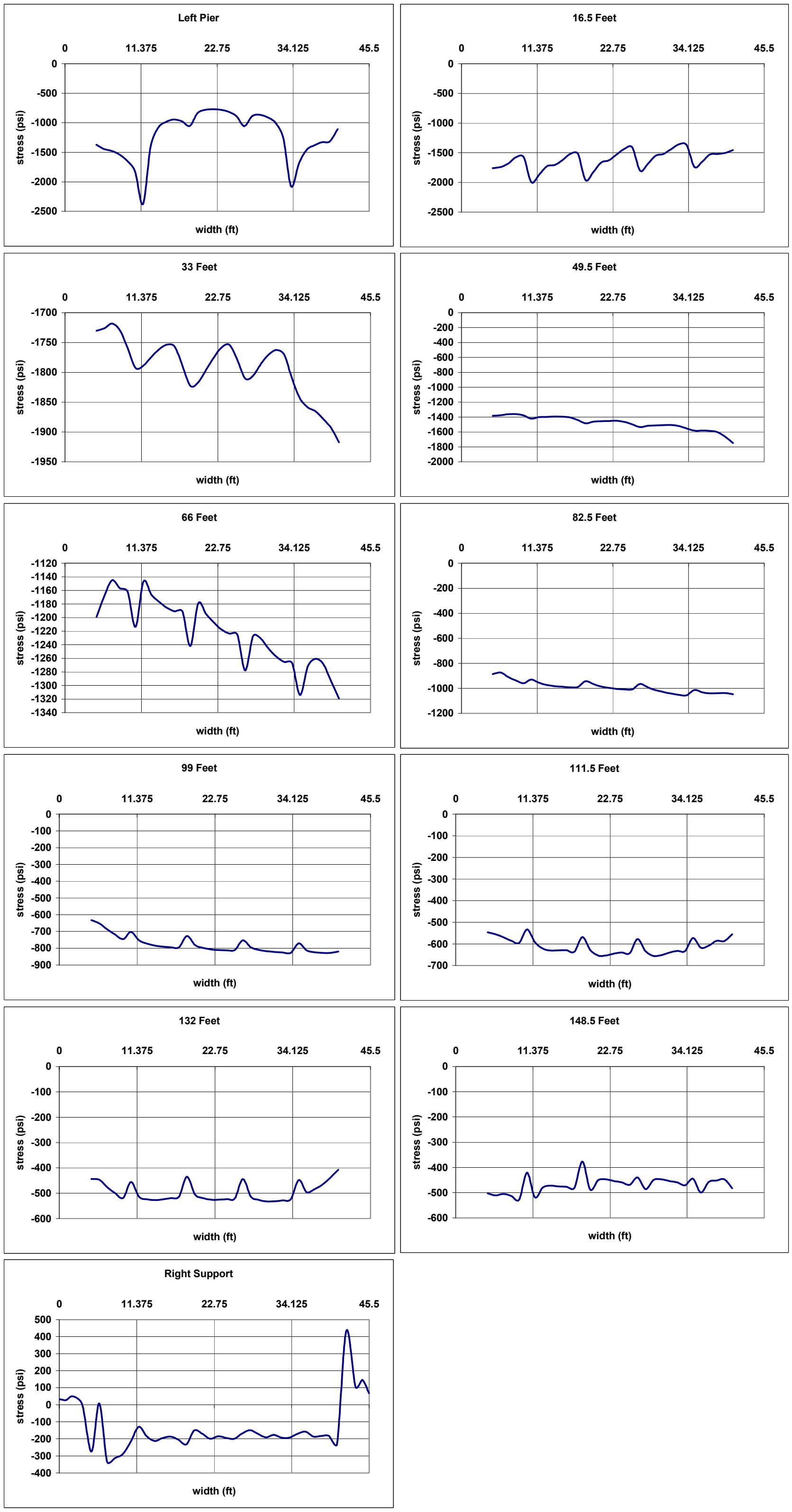

Figure D.12 Bridge I871E, Span 2, Stage 3, Bottom Fiber

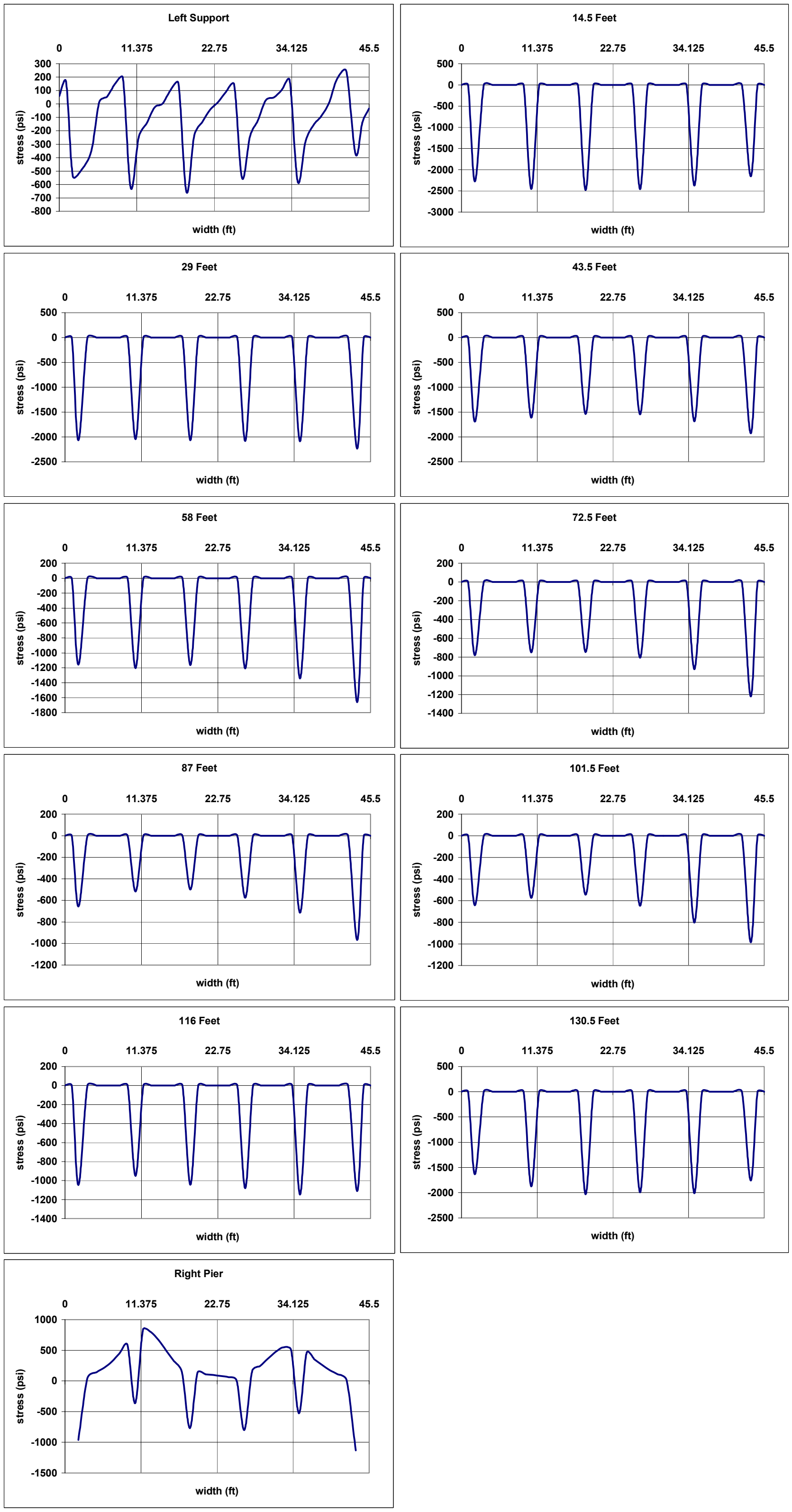

Figure D.13 Bridge I871E, Span 1, Stage 3 Alternative, Top Fiber

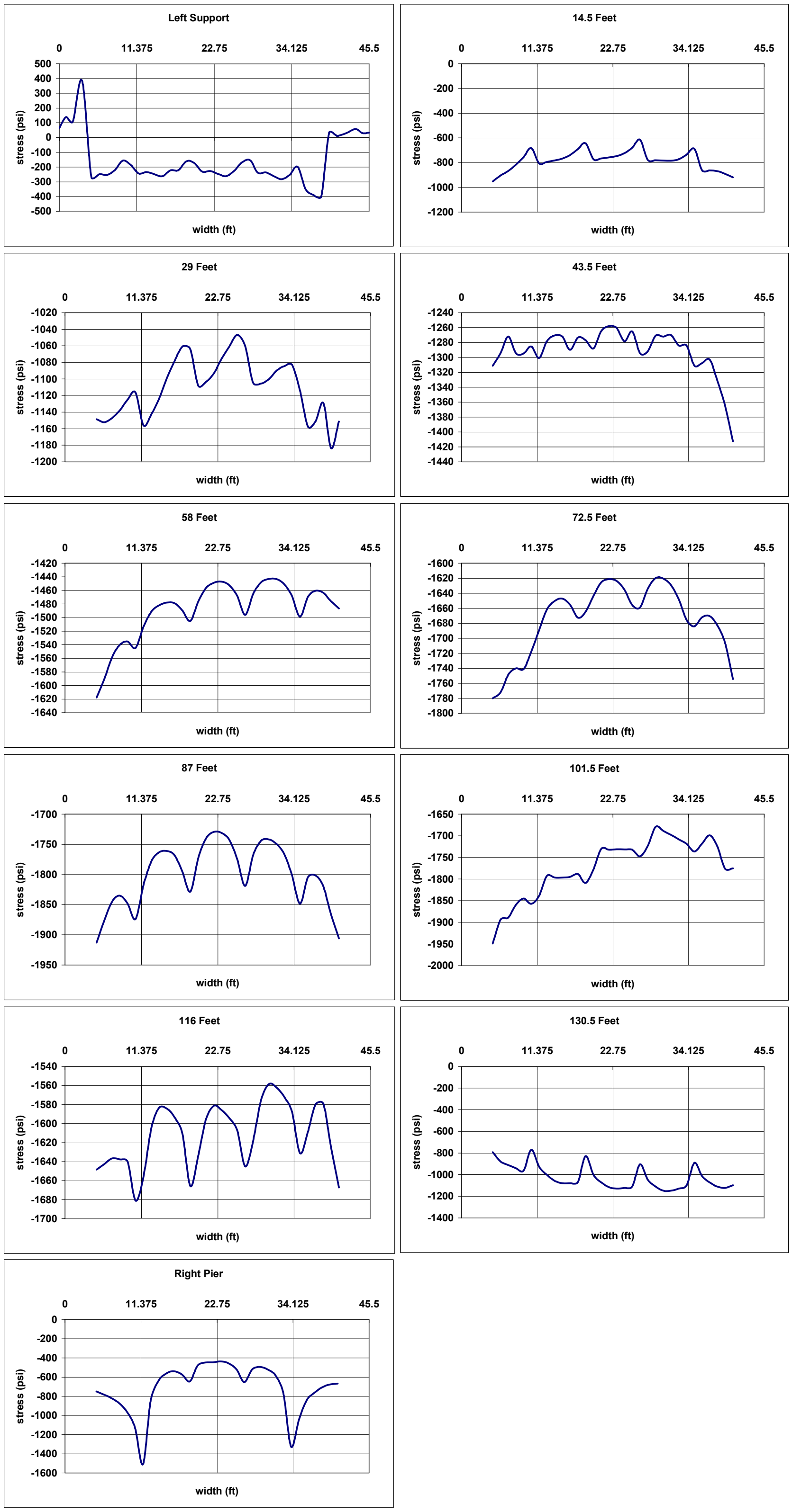

Figure D.14 Bridge I871E, Span 1, Stage 3 Alternative, Bottom Fiber

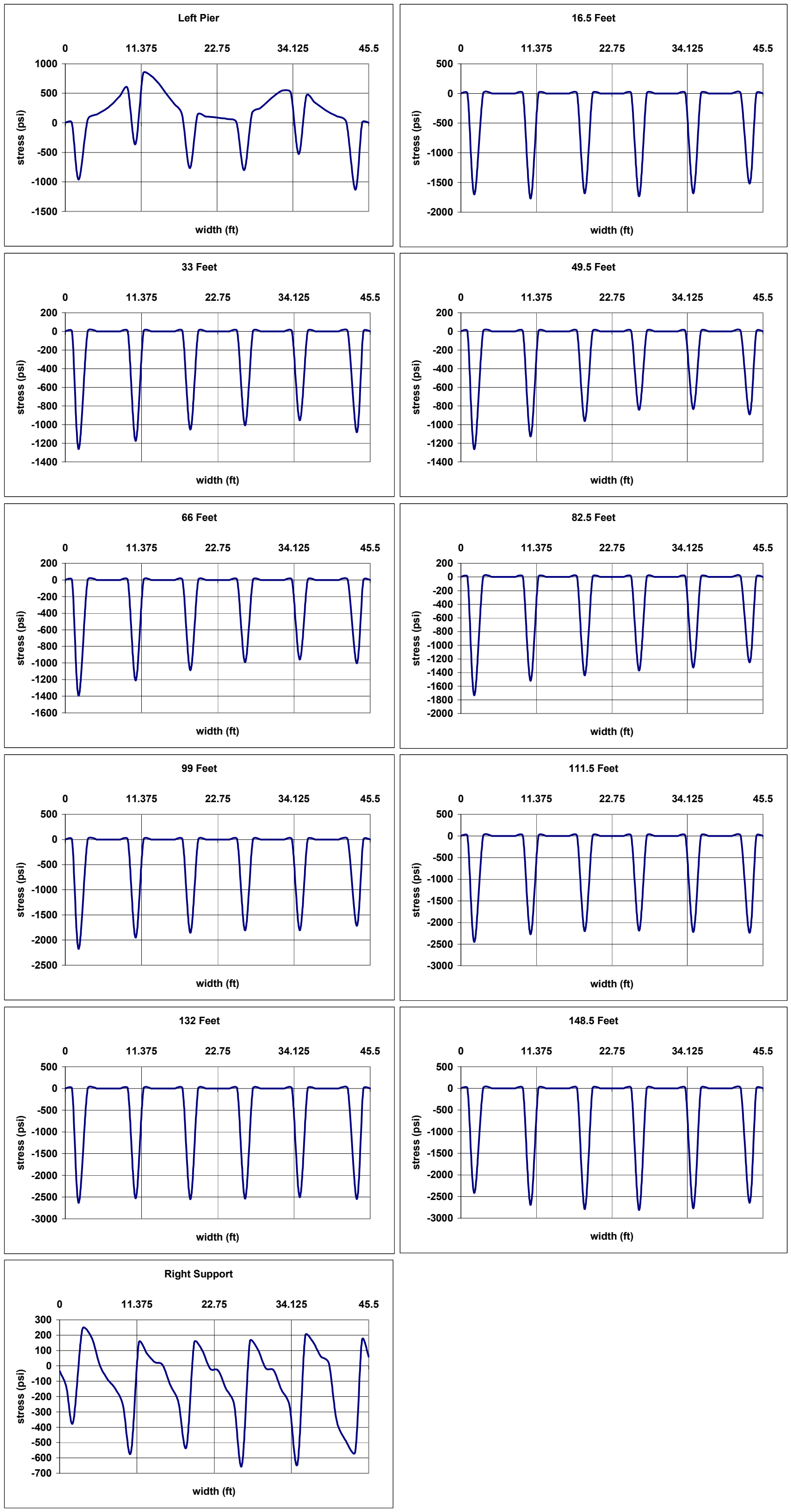

Figure D.15 Bridge I871E, Span 2, Stage 3 Alternative, Top Fiber

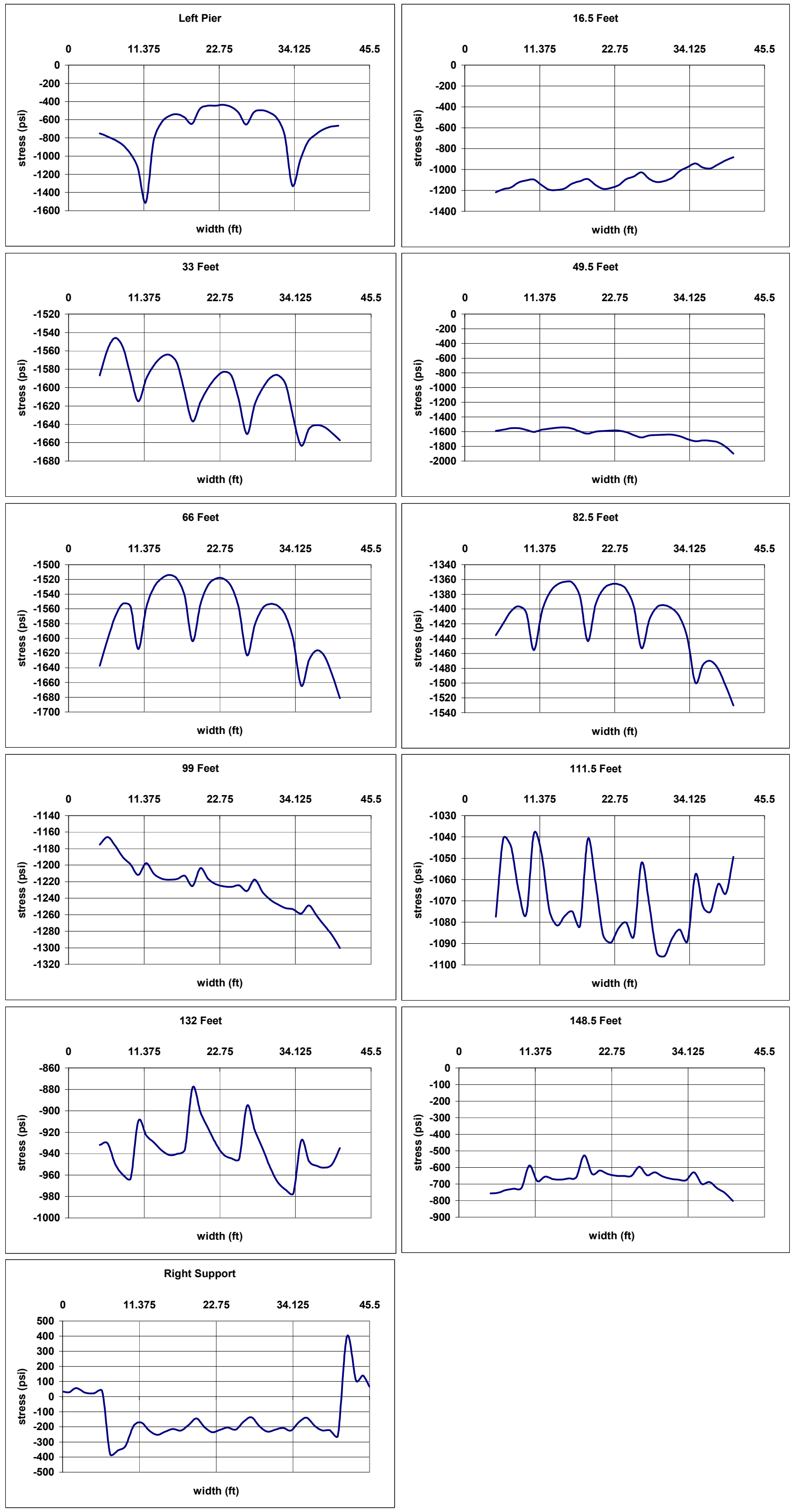

Figure D.16 Bridge I871E, Span 2, Stage 3 Alternative, Bottom Fiber

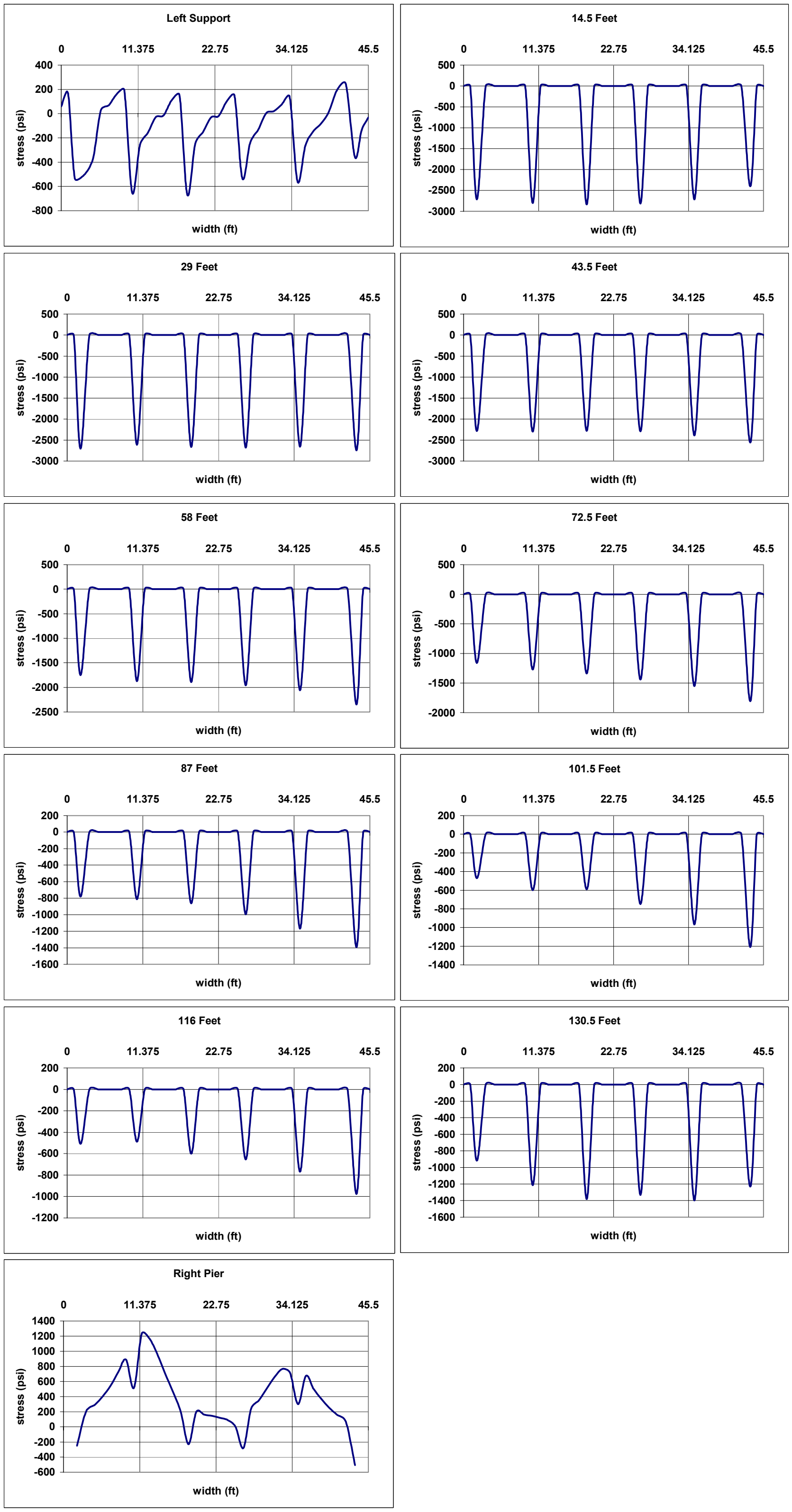

Figure D.17 Bridge I871E, Span 1, Stage 4, Top Fiber

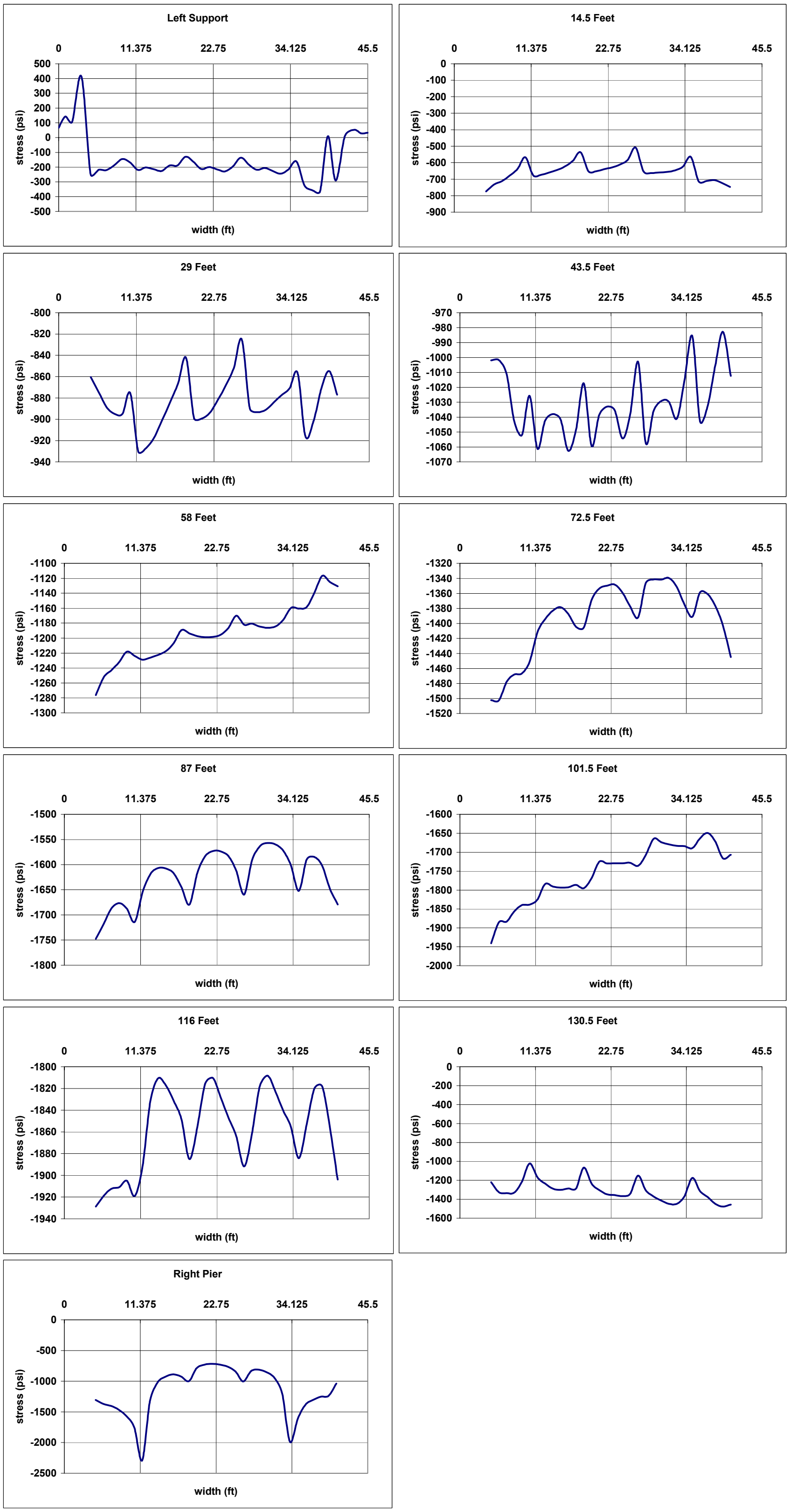

Figure D.18 Bridge I871E, Span 1, Stage 4, Bottom Fiber

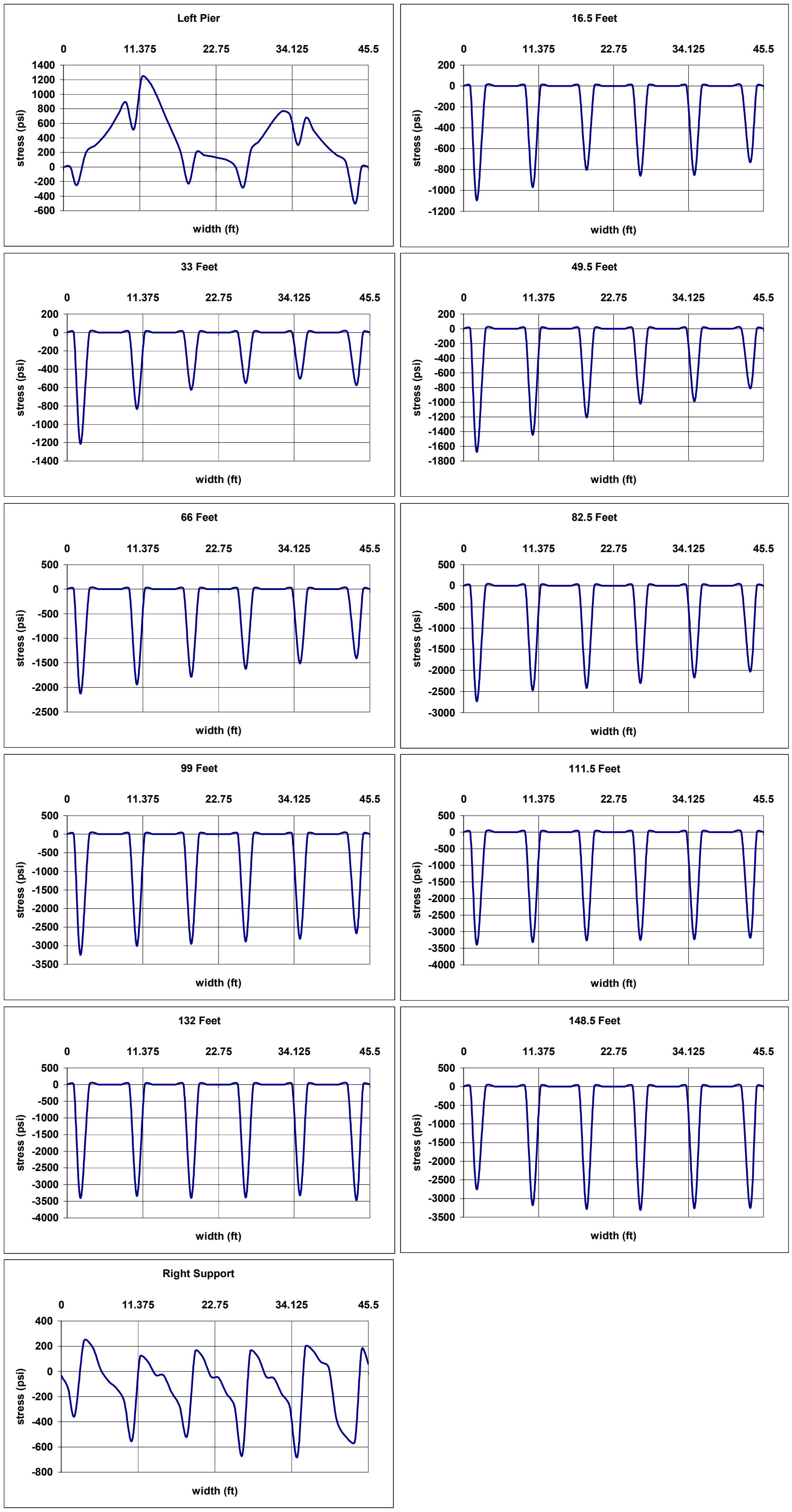

Figure D.19 Bridge I871E, Span 2, Stage 4, Top Fiber

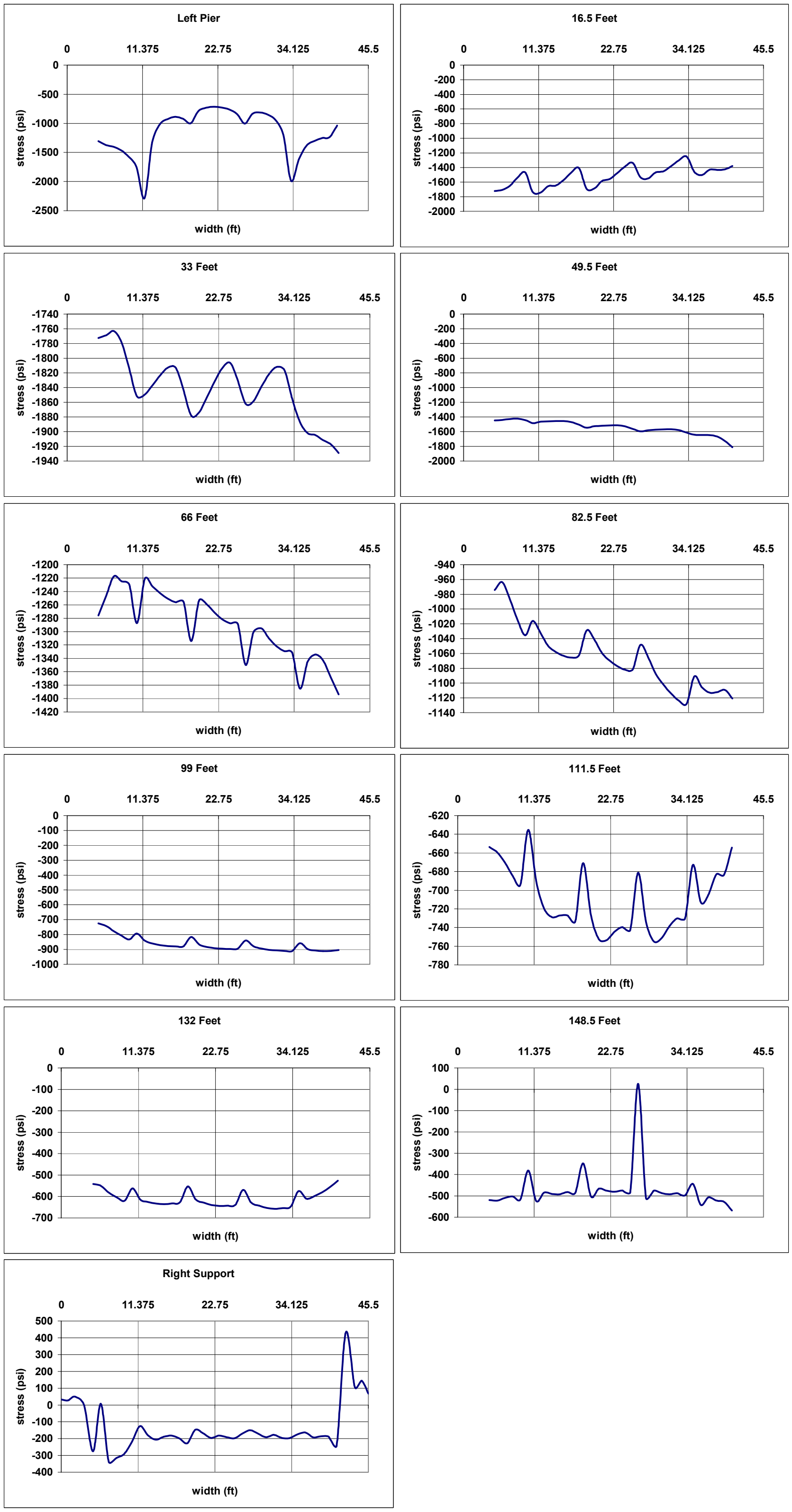

Figure D.20 Bridge I871E, Span 2, Stage 4, Bottom Fiber

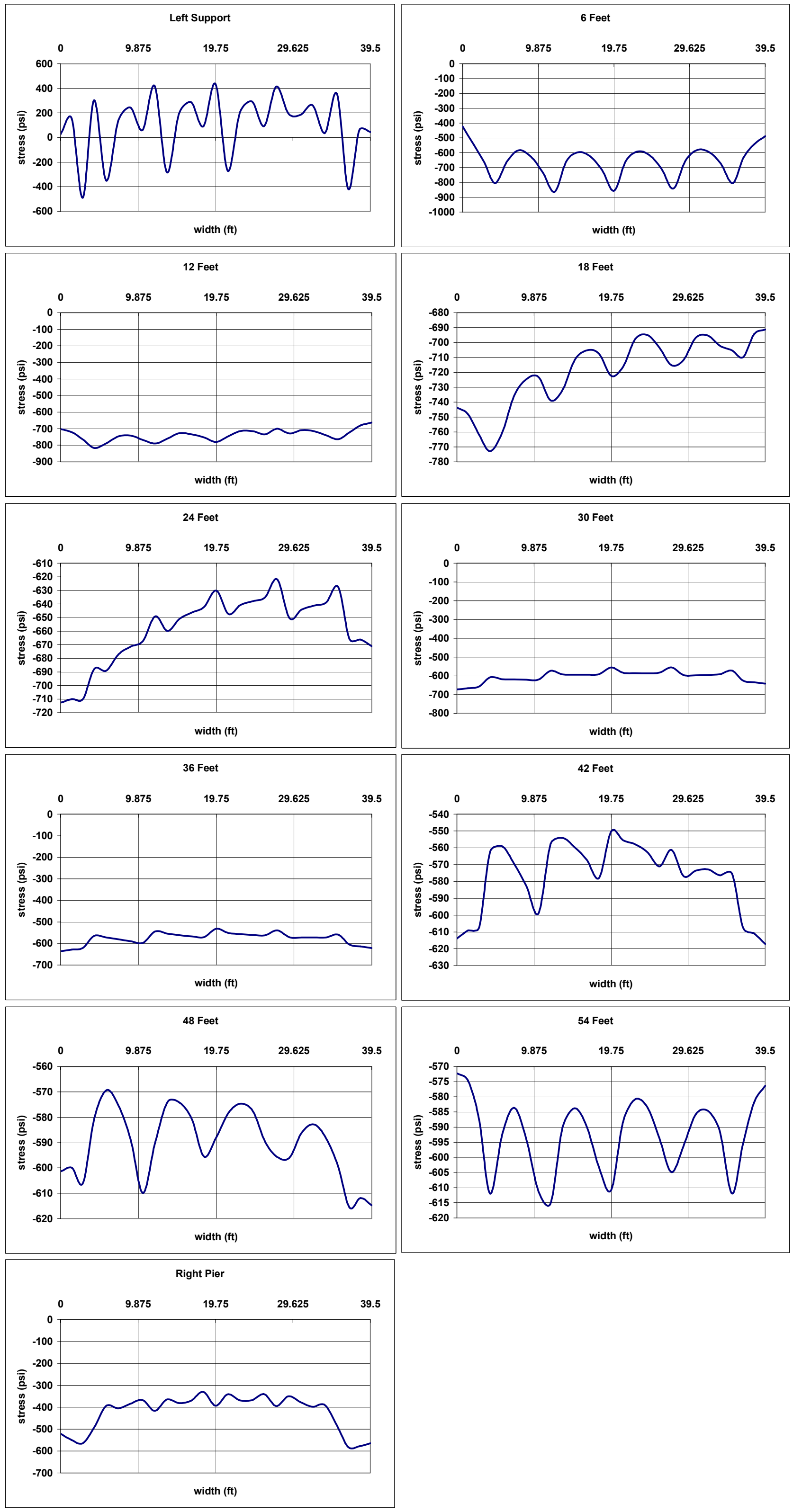

Figure D.21 Bridge I873, Span 1, Stage 1, Top Fiber

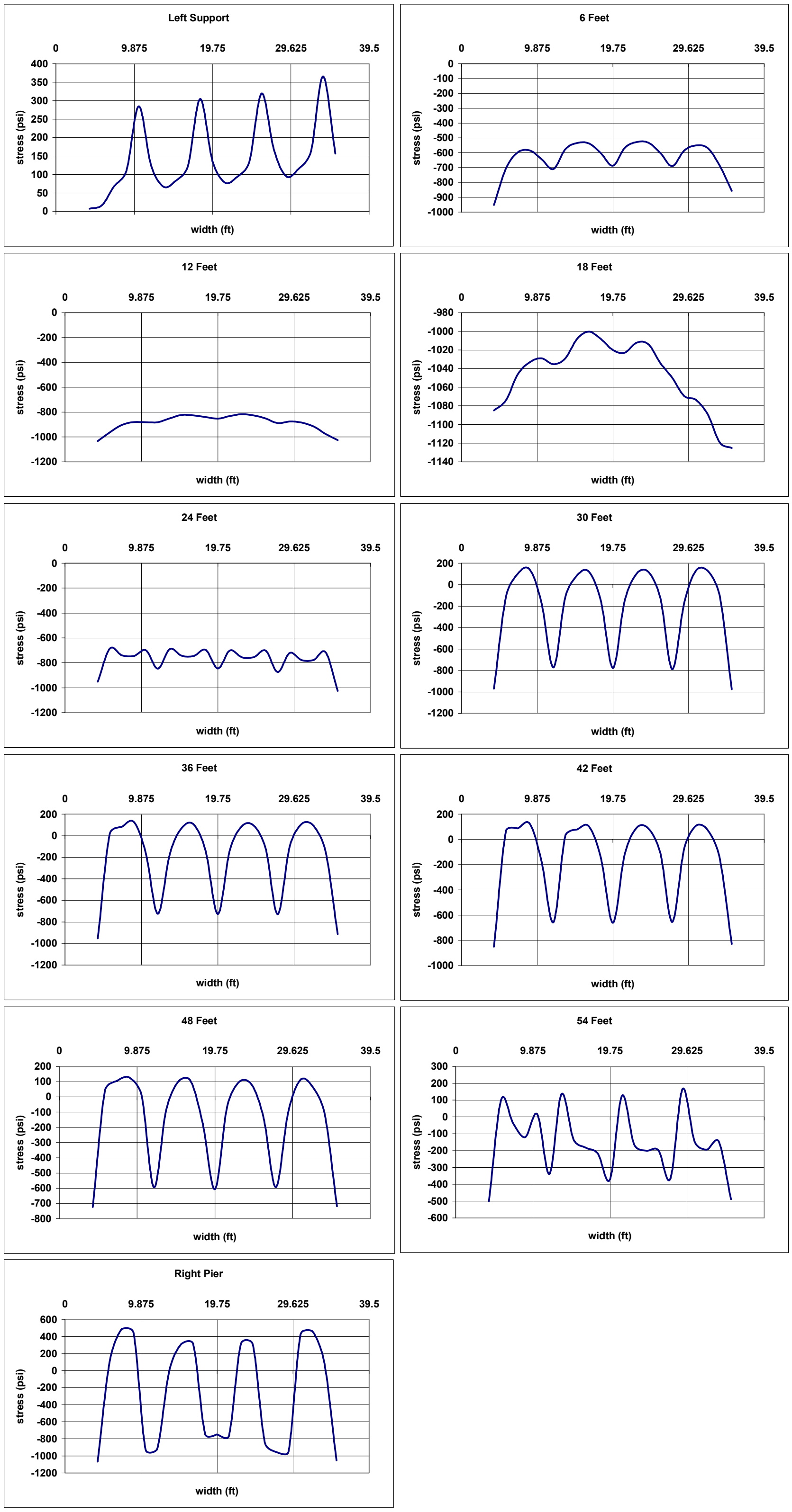

Figure D.22 Bridge I873, Span 1, Stage 1, Bottom Fiber

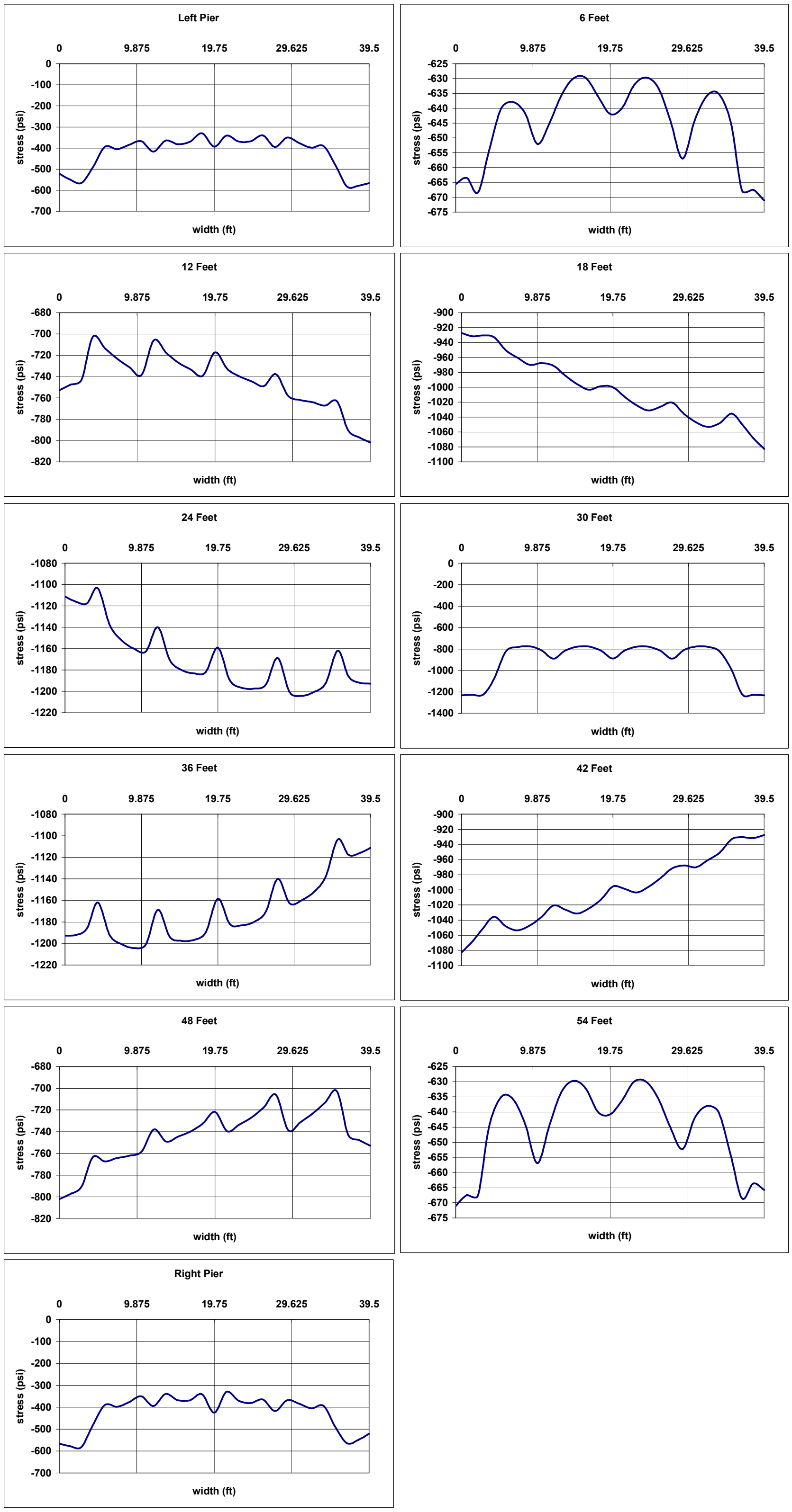

Figure D.23 Bridge I873, Span 2, Stage 1, Top Fiber

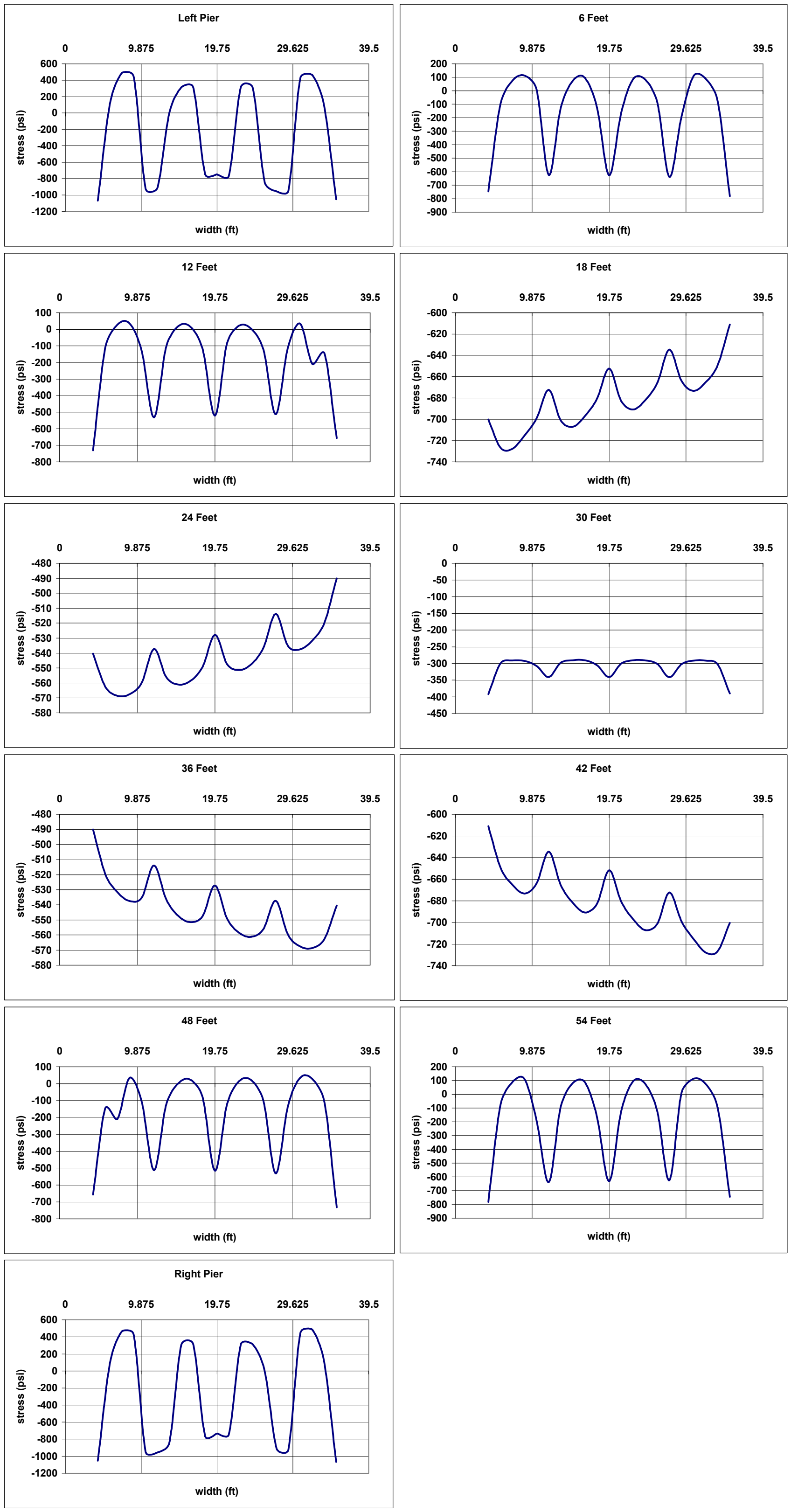

Figure D.24 Bridge I873, Span 2, Stage 1, Bottom Fiber

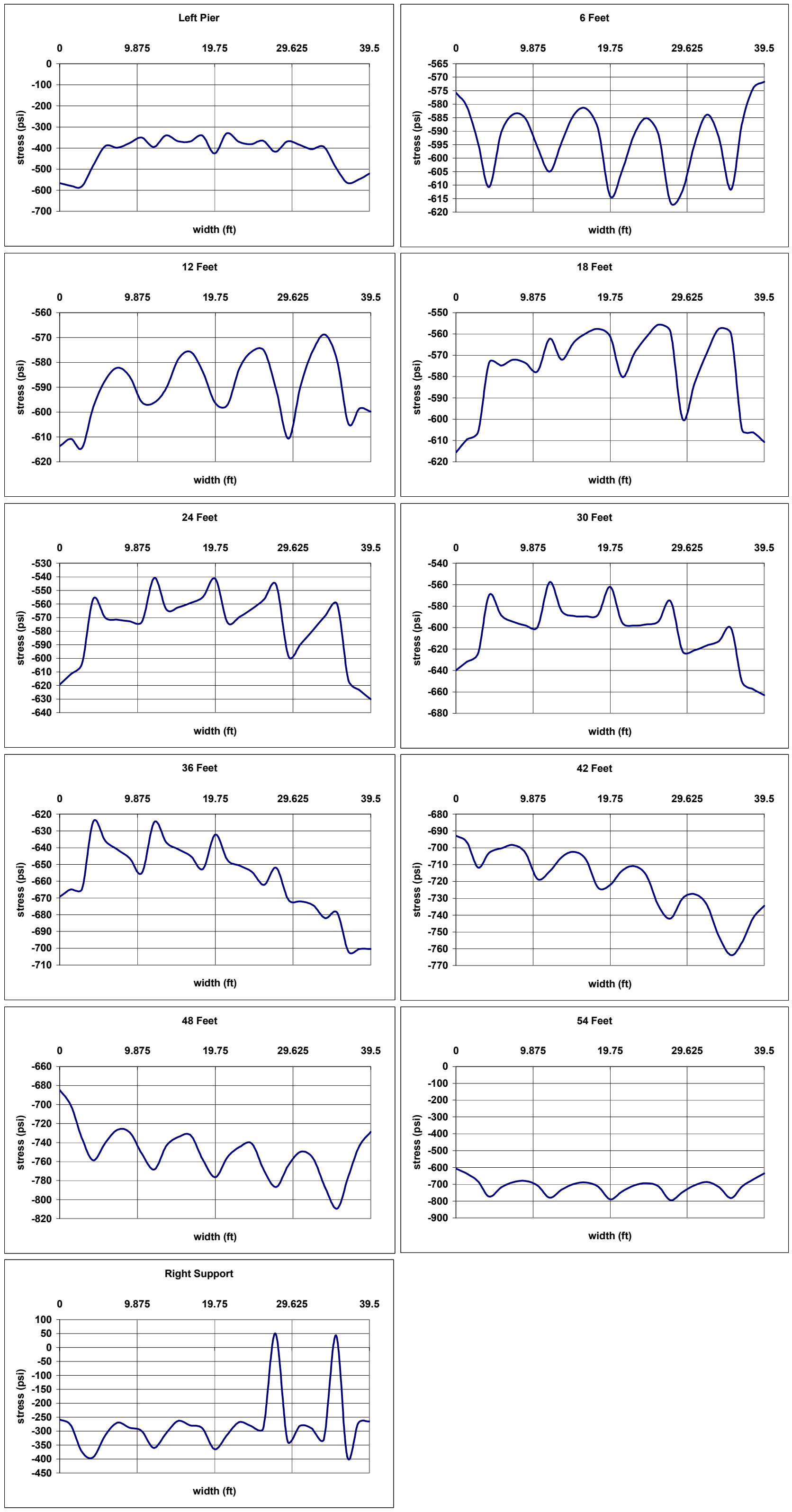

Figure D.25 Bridge I873, Span 3, Stage 1, Top Fiber

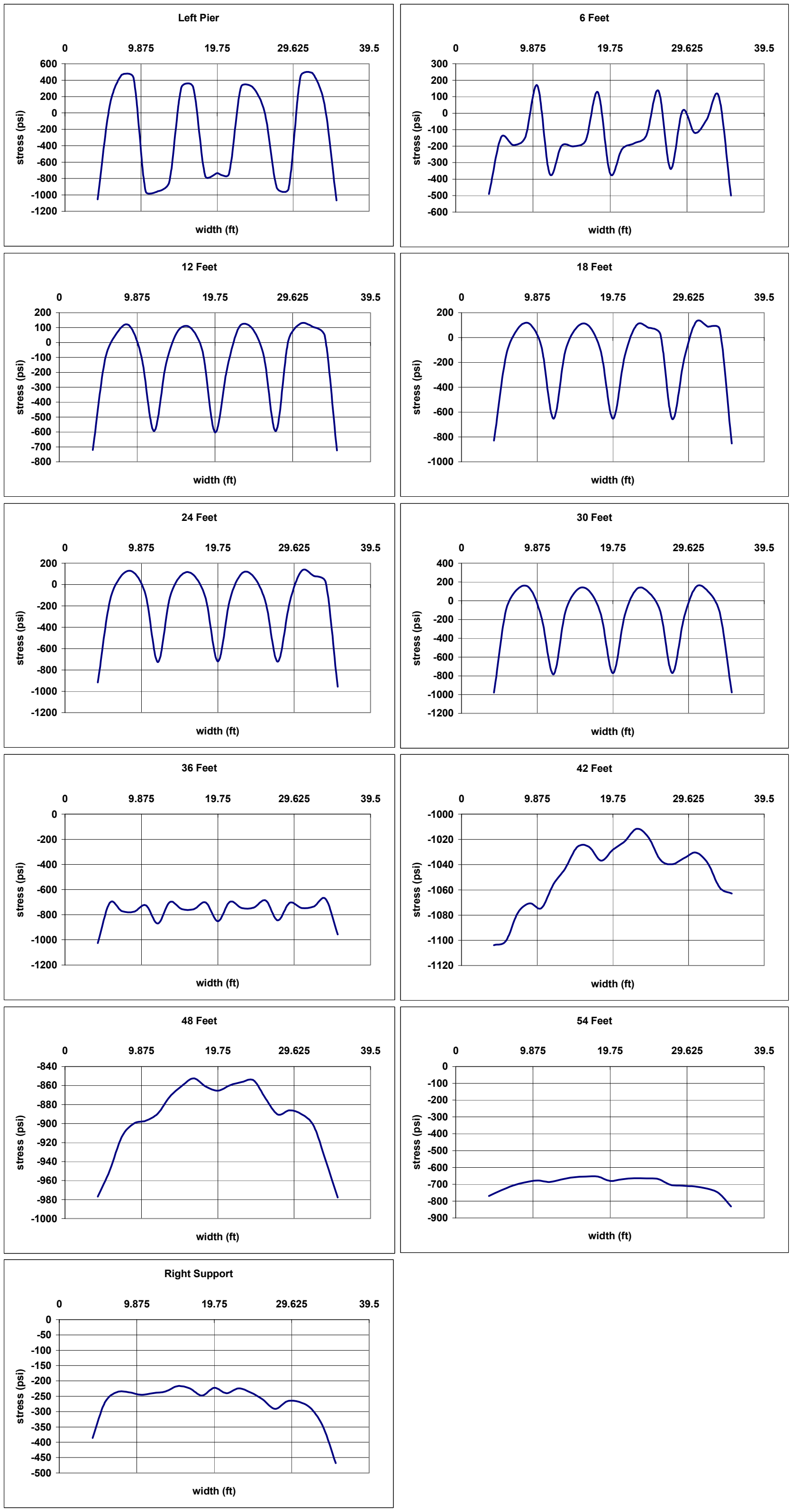

Figure D.26 Bridge I873, Span 3, Stage 1, Bottom Fiber

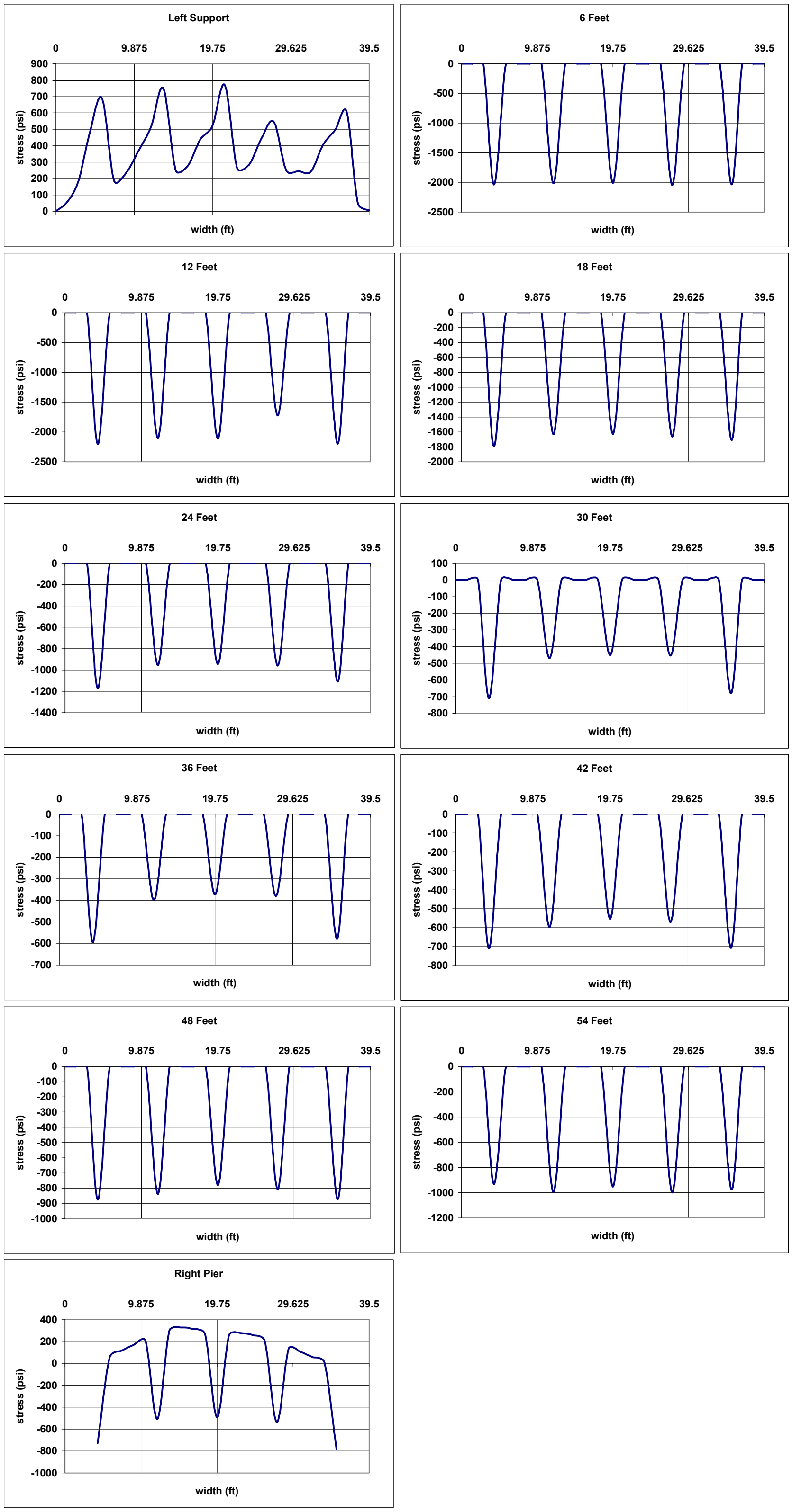

Figure D.27 Bridge I873, Span 1, Stage 2, Top Fiber

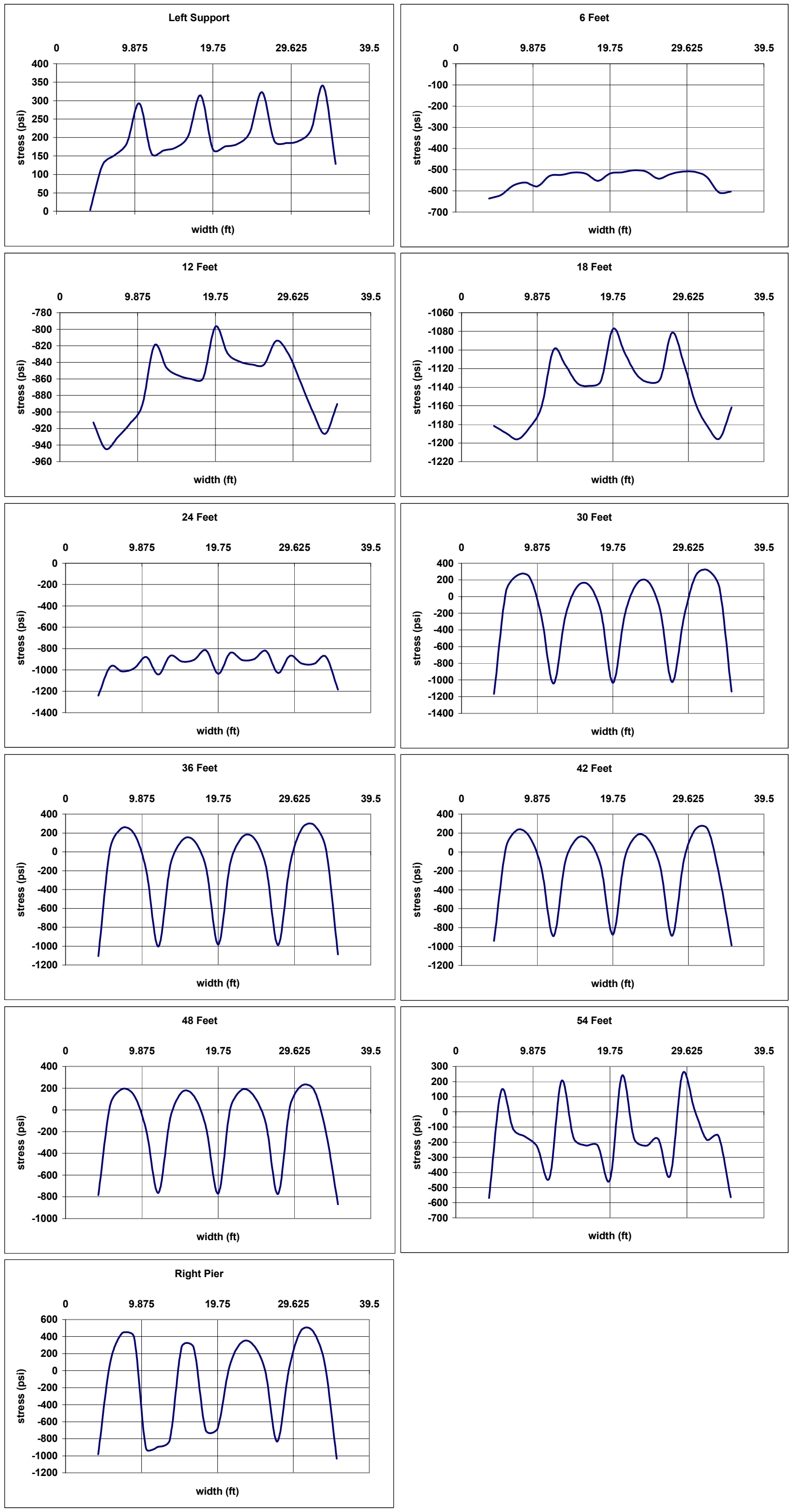

Figure D.28 Bridge I873, Span 1, Stage 2, Bottom Fiber

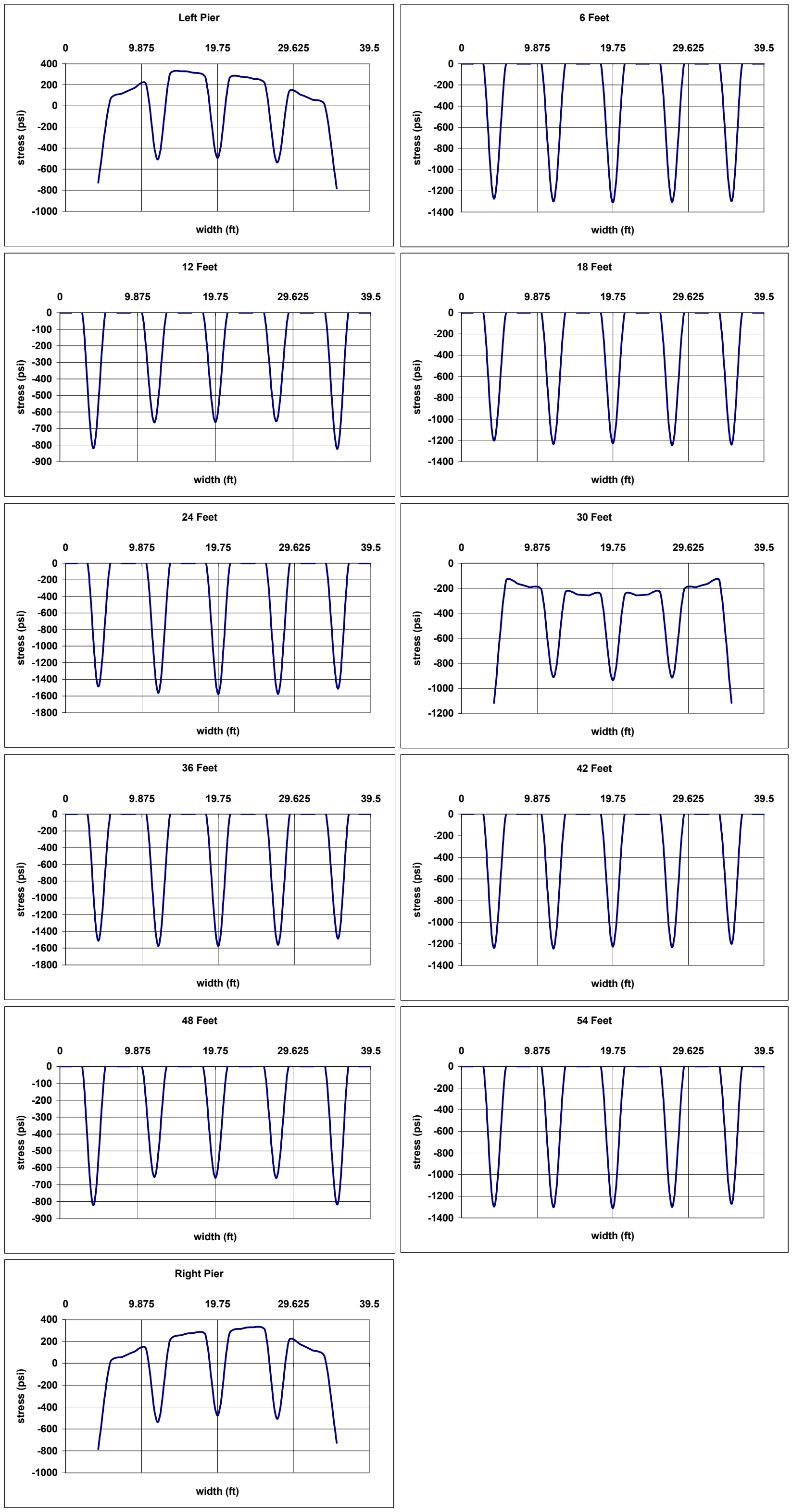

Figure D.29 Bridge I873, Span 2, Stage 2, Top Fiber

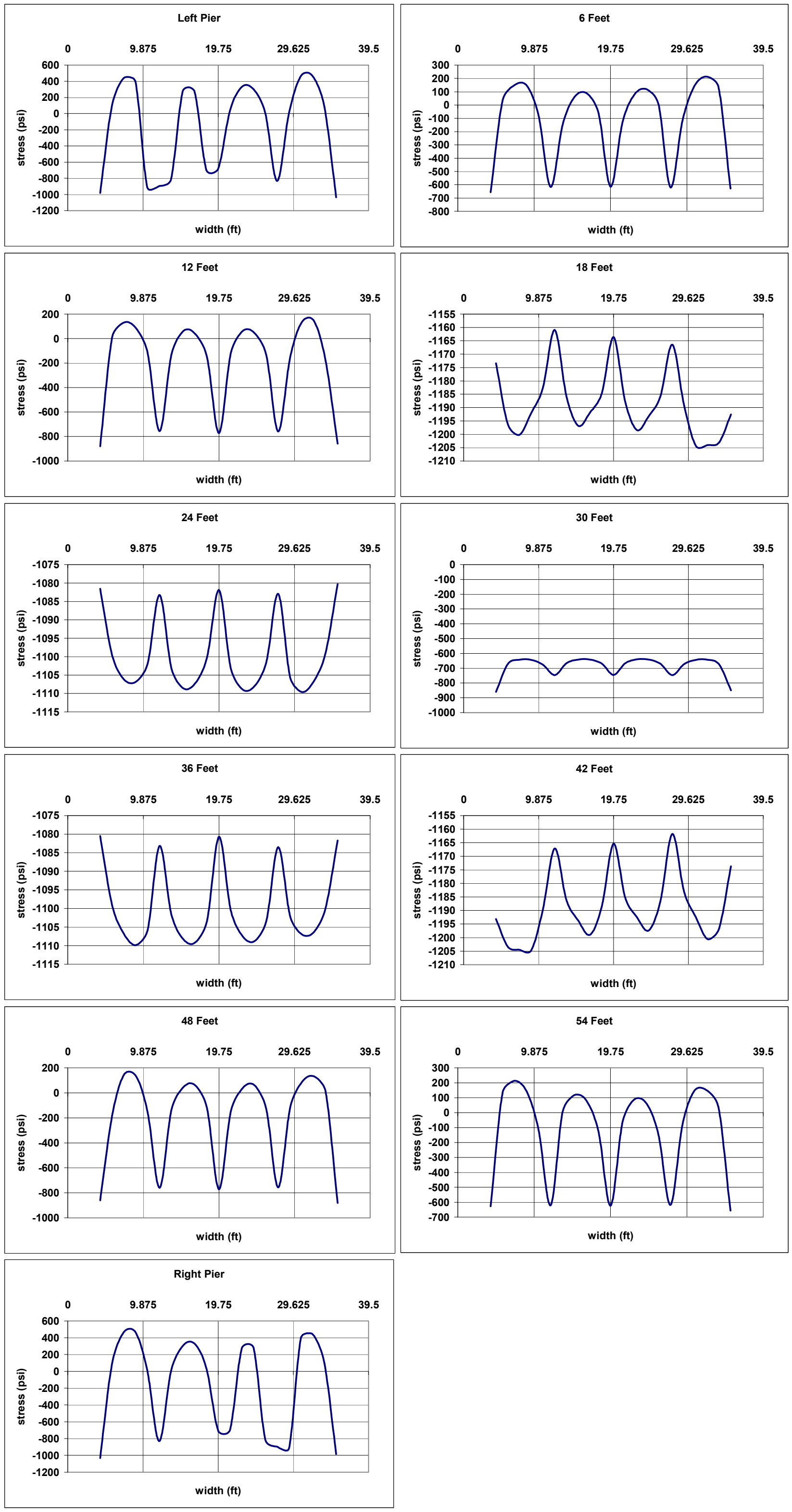

Figure D.30 Bridge I873, Span 2, Stage 2, Bottom Fiber

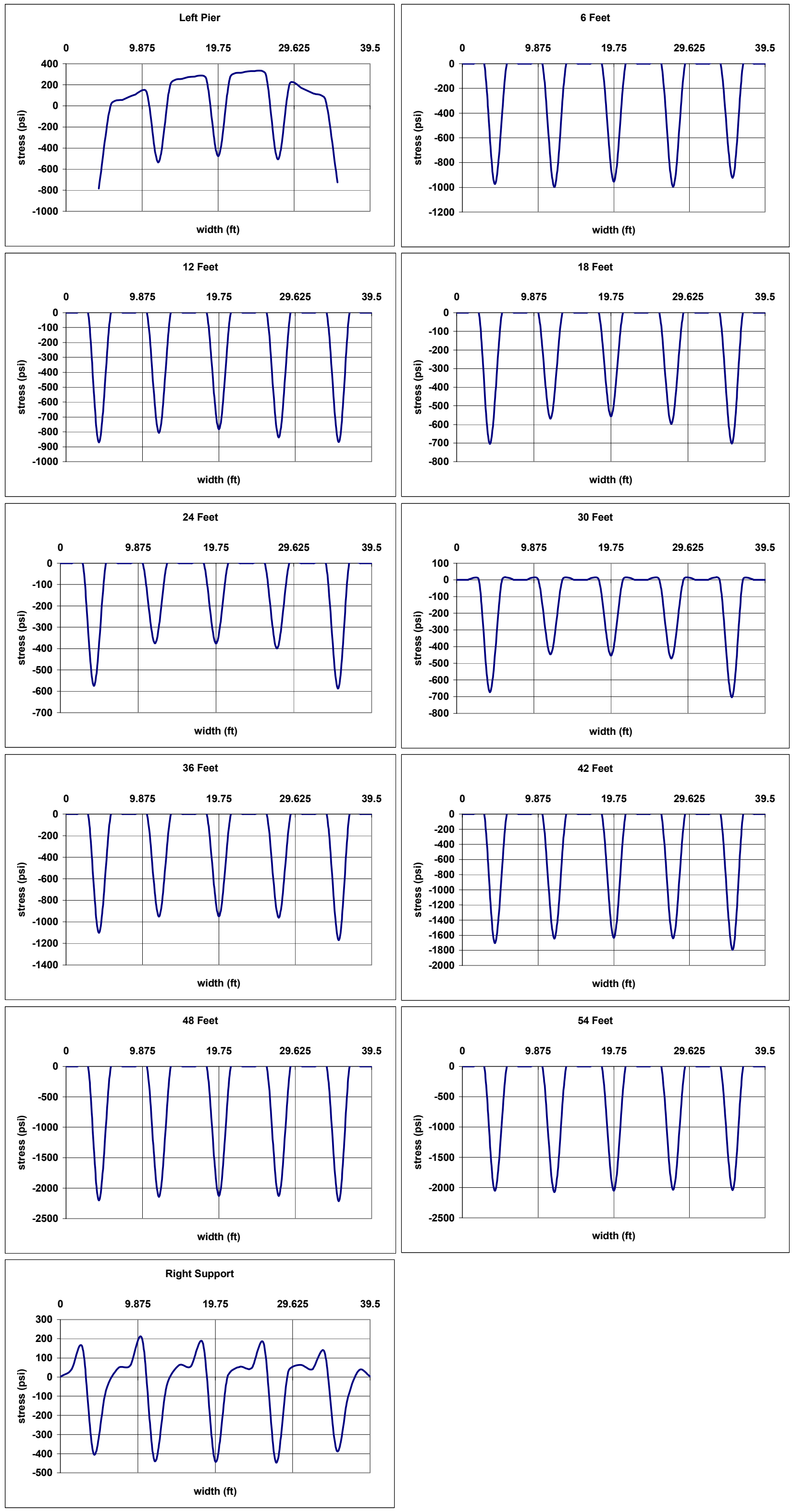

Figure D.31 Bridge I873, Span 3, Stage 2, Top Fiber

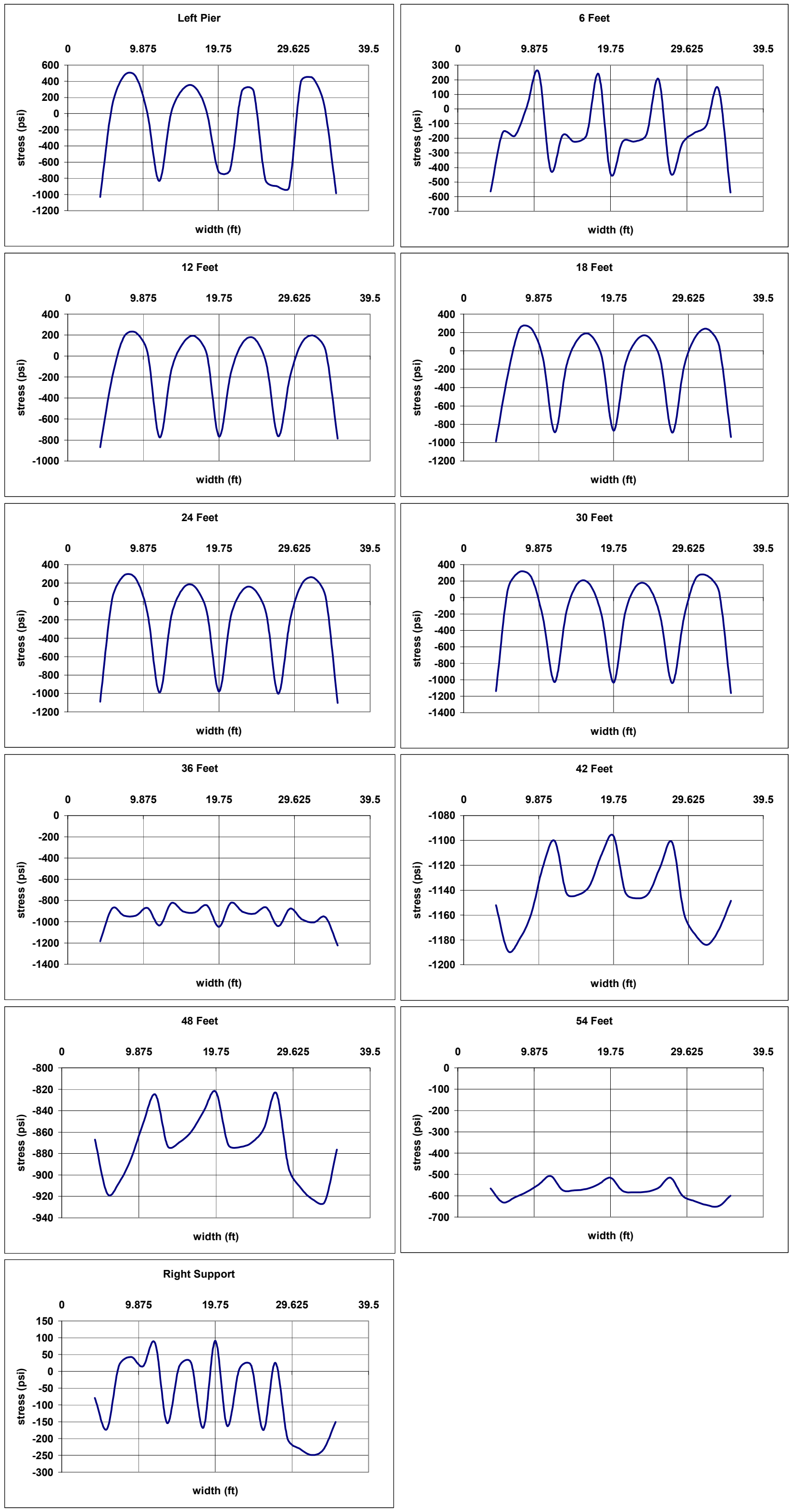

Figure D.32 Bridge I873, Span 3, Stage 2, Bottom Fiber

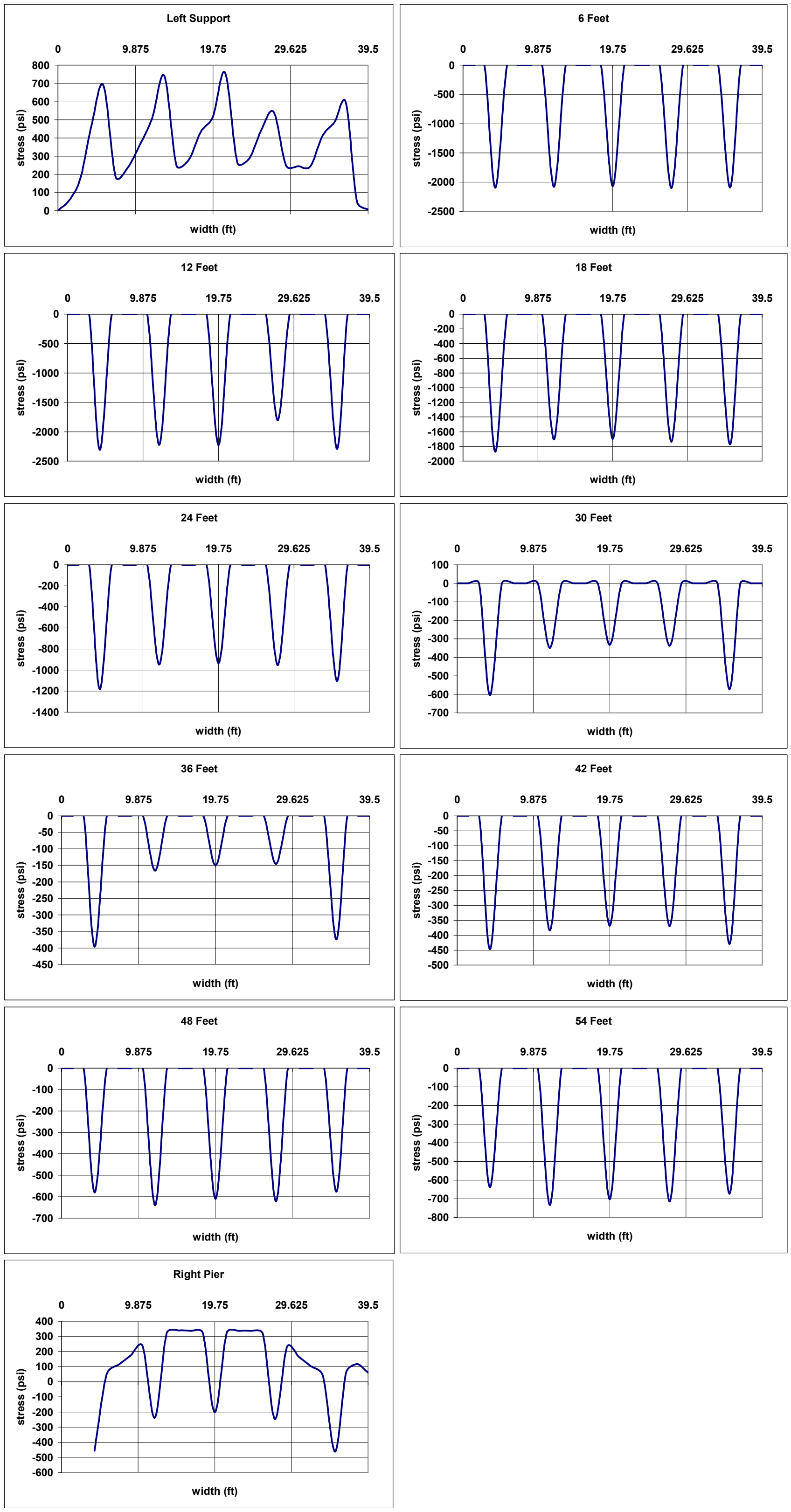

Figure D.33 Bridge I873, Span 1, Stage 3, Top Fiber

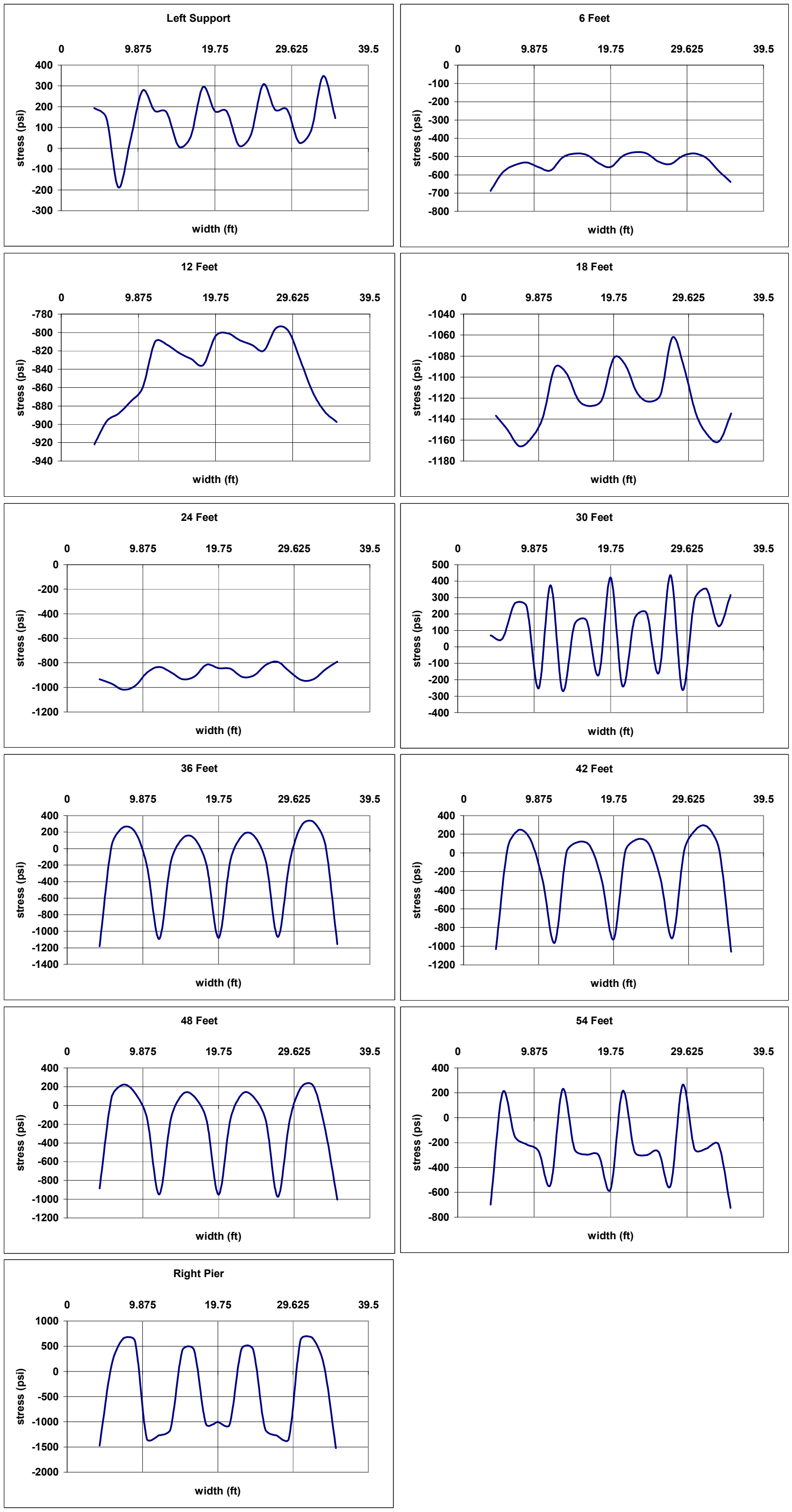

Figure D.34 Bridge I873, Span 1, Stage 3, Bottom Fiber

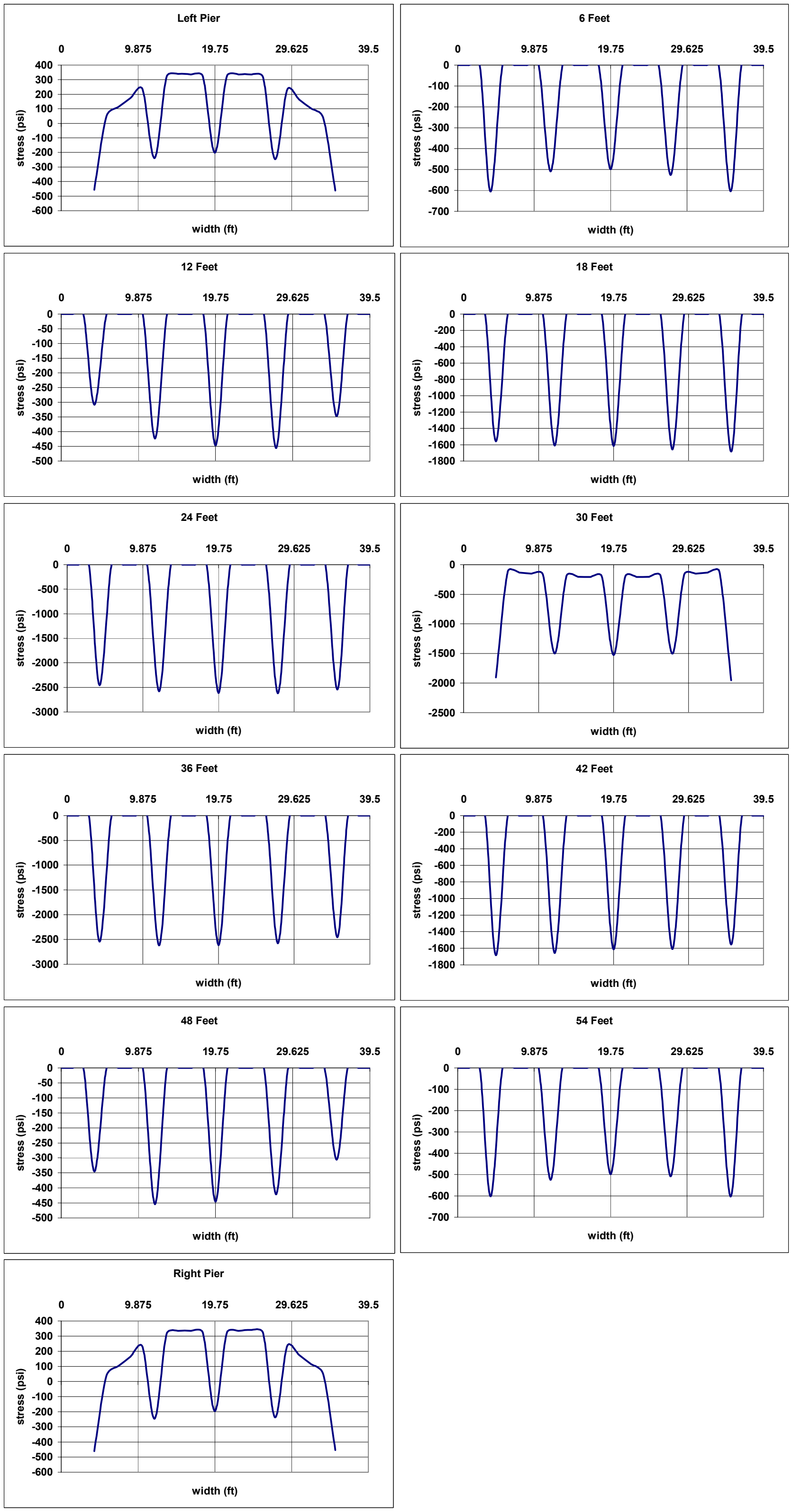

Figure D.35 Bridge I873, Span 2, Stage 3, Top Fiber

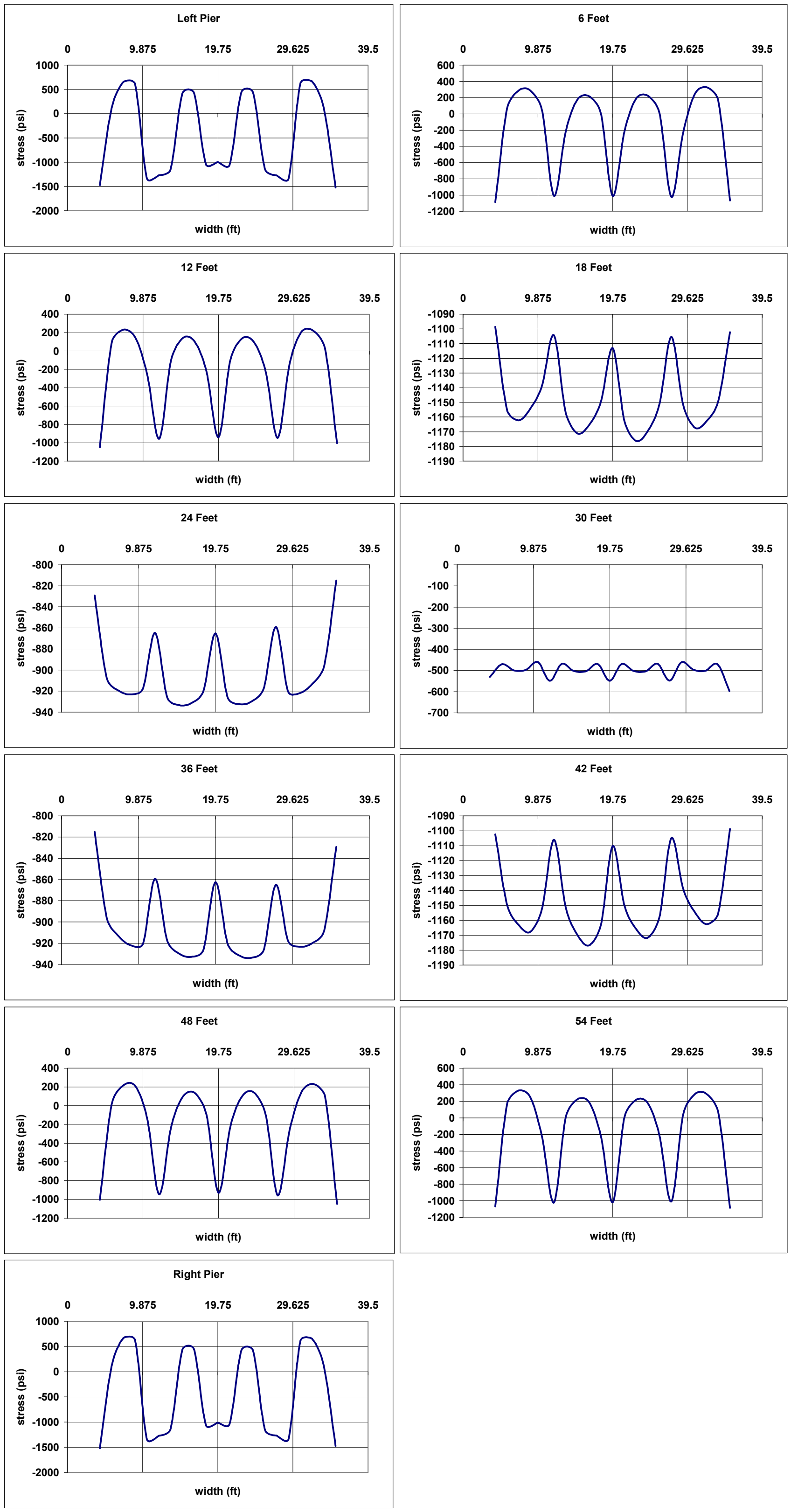

Figure D.36 Bridge I873, Span 2, Stage 3, Bottom Fiber

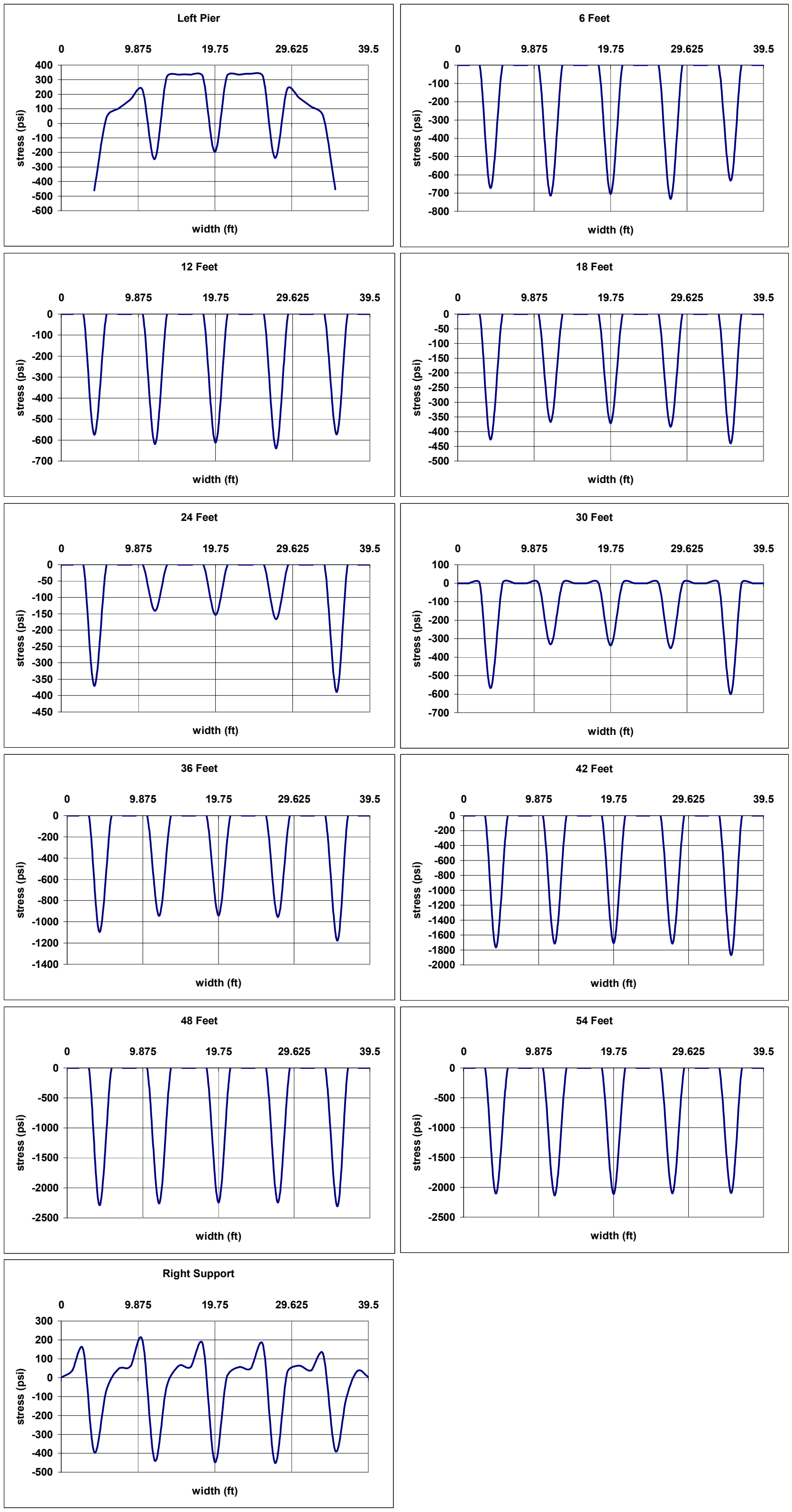

Figure D.37 Bridge I873, Span 3, Stage 3, Top Fiber

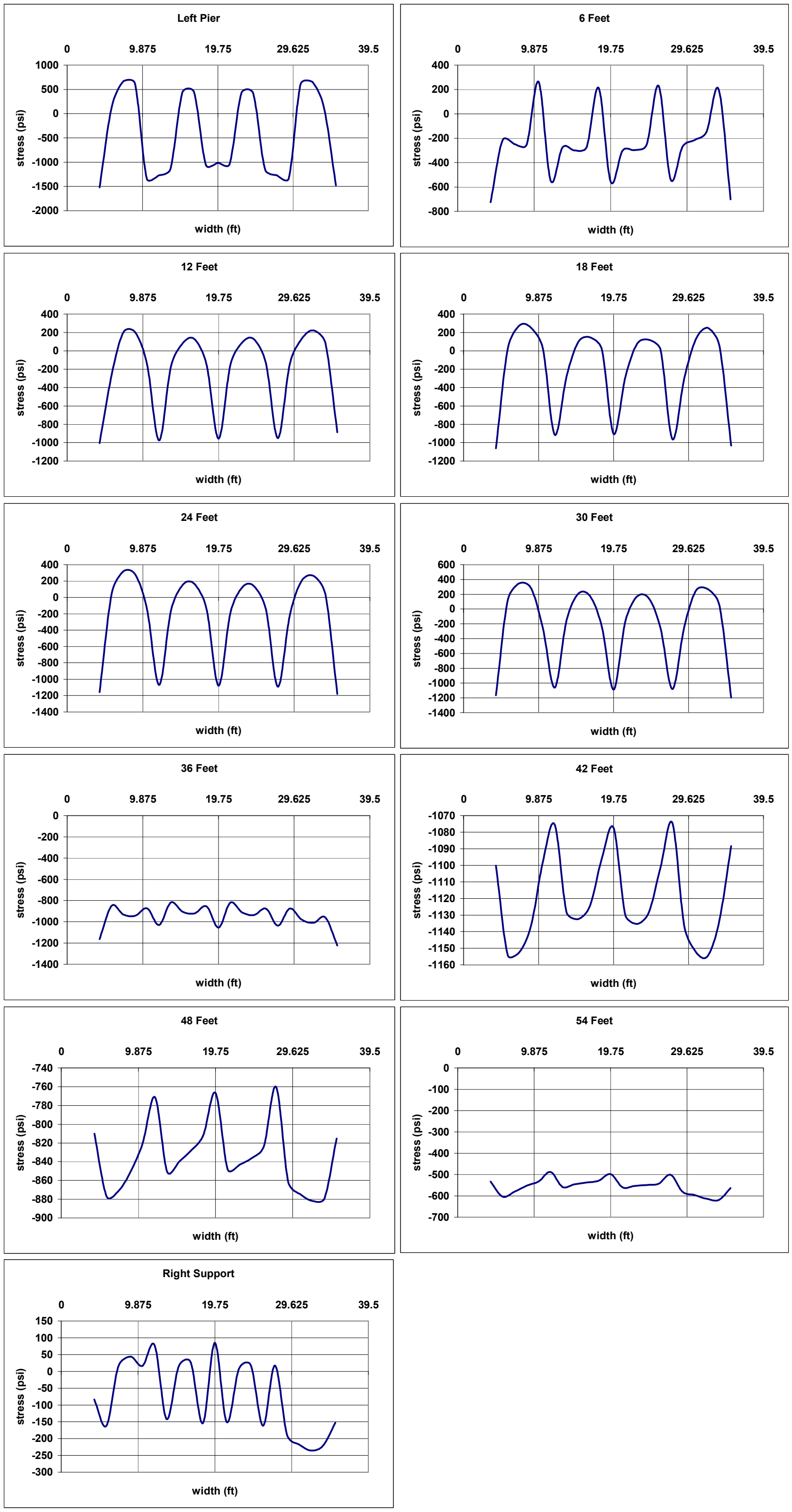

Figure D.38 Bridge I873, Span 3, Stage 3, Bottom Fiber

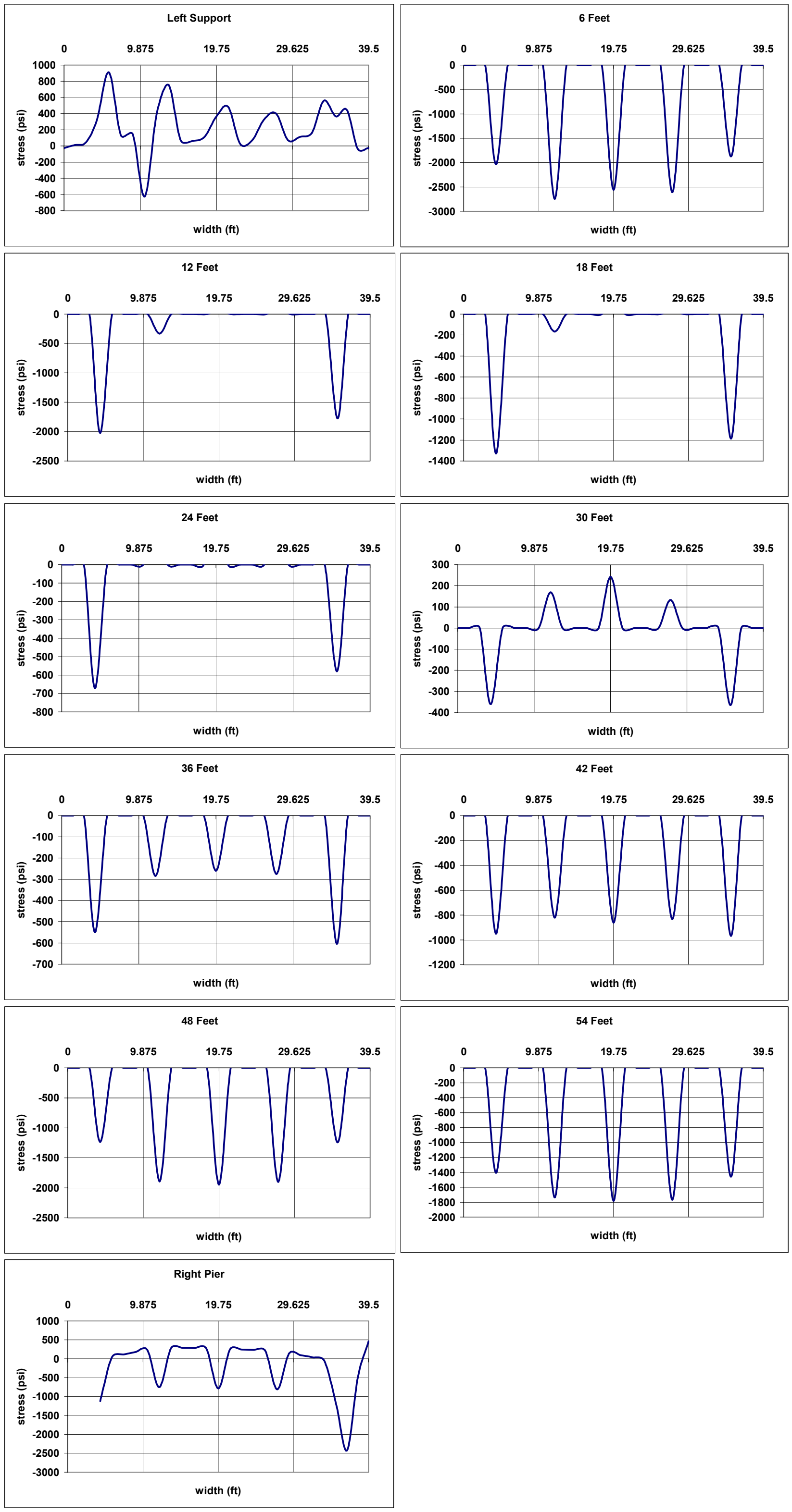

Figure D.39 Bridge I873, Span 1, Stage 3 Alternative, Top Fiber

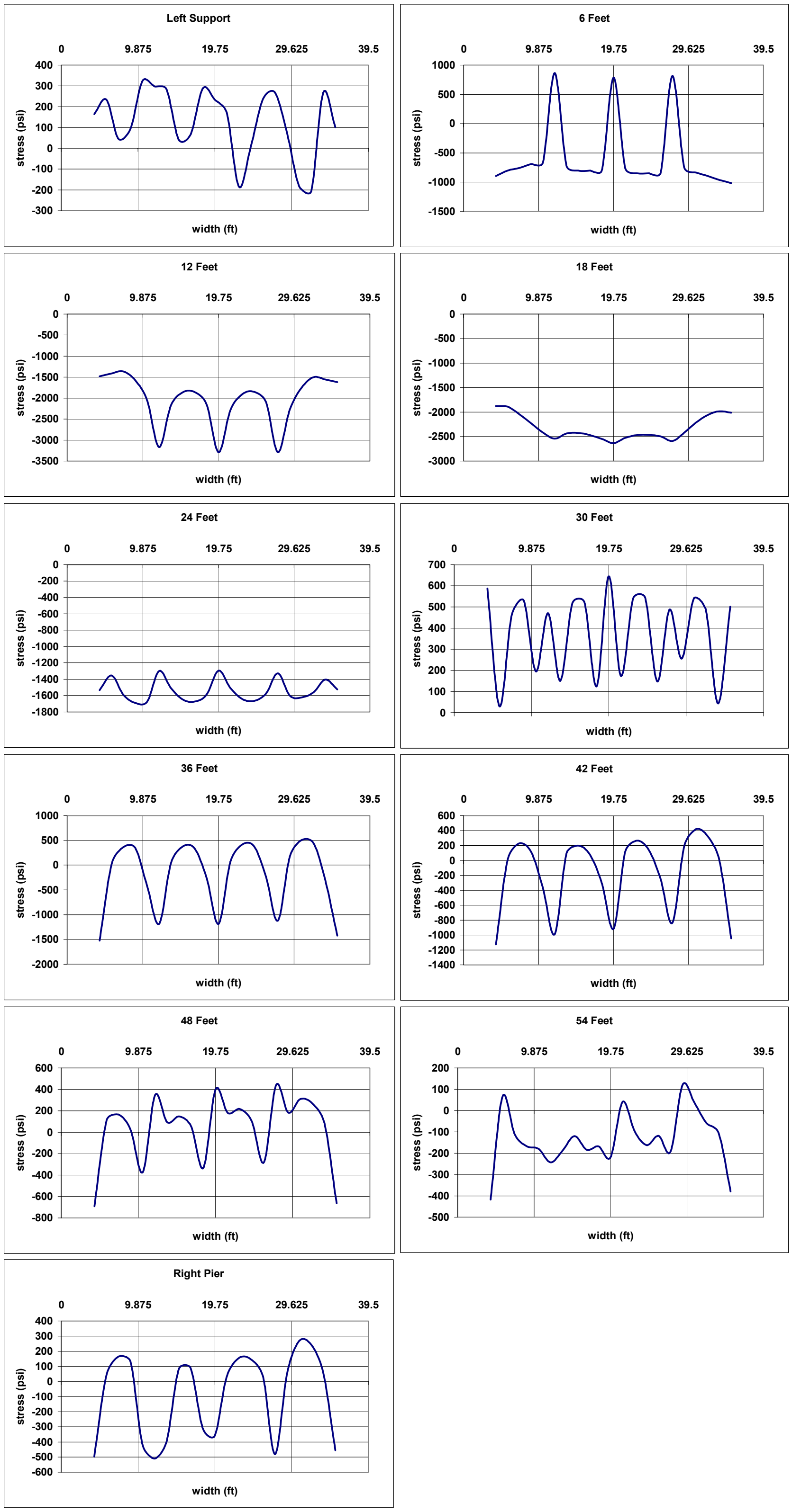

Figure D.40 Bridge I873, Span 1, Stage 3 Alternative, Bottom Fiber

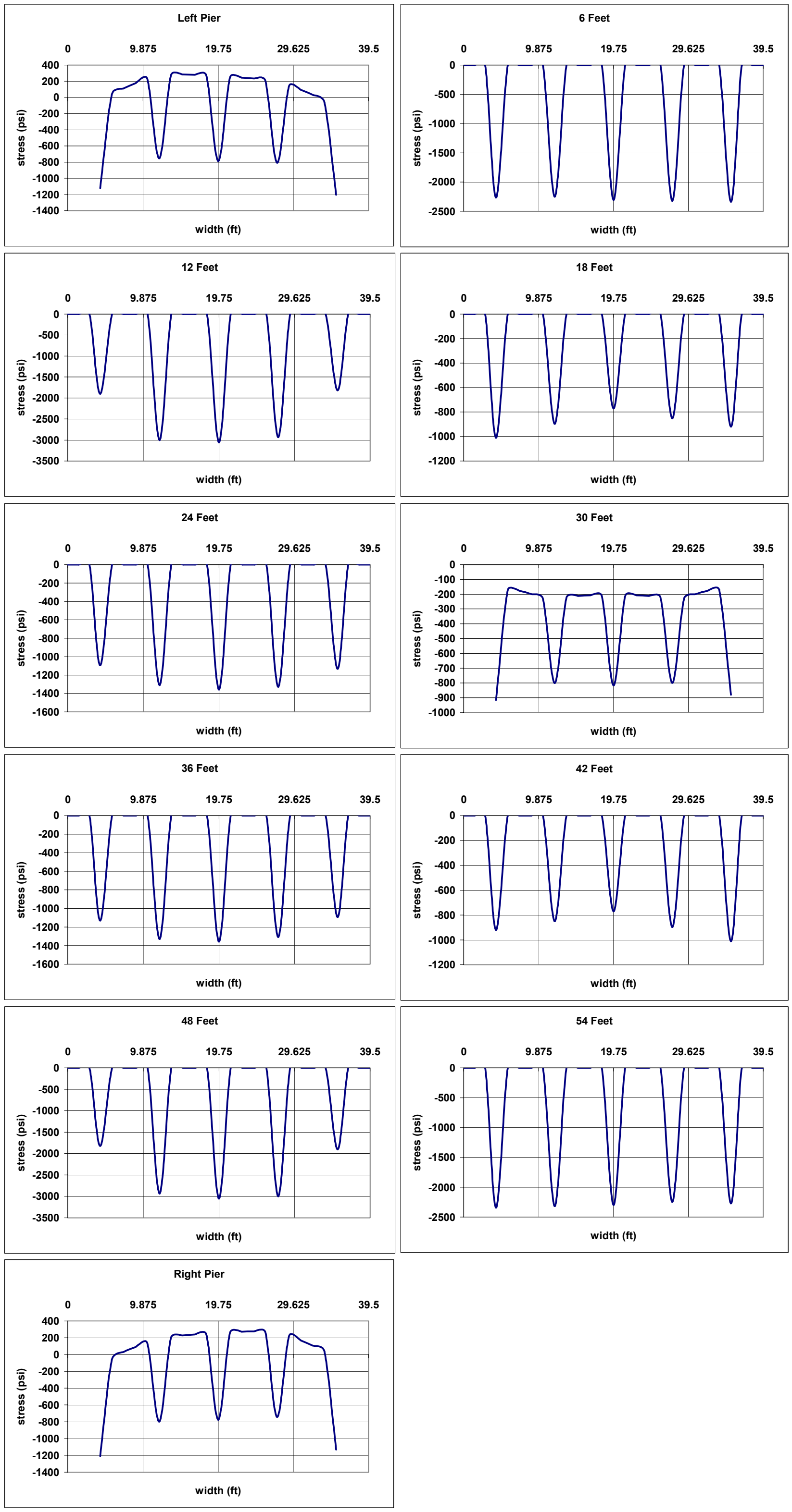

Figure D.41 Bridge I873, Span 2, Stage 3 Alternative, Top Fiber

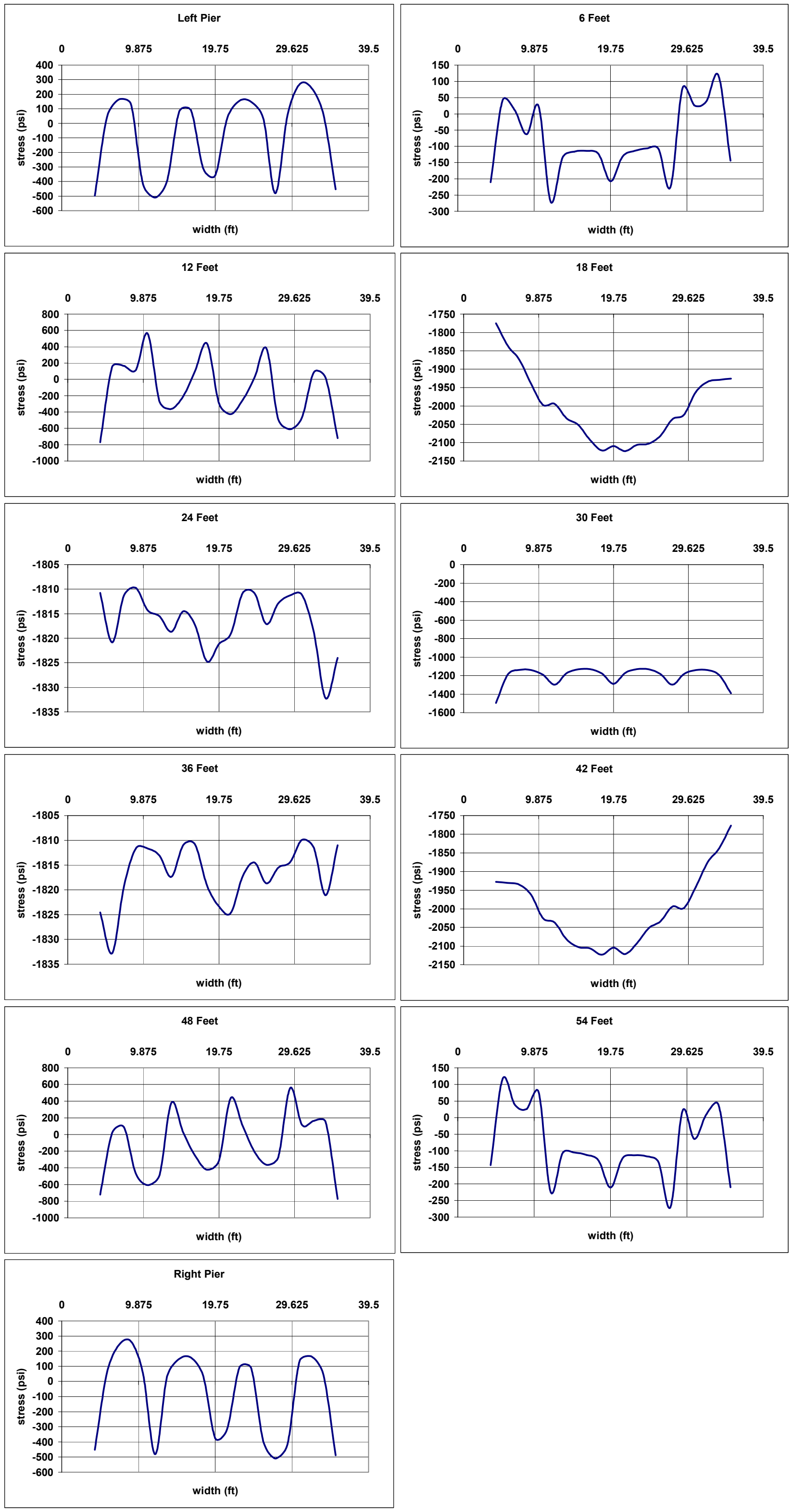

Figure D.42 Bridge I873, Span 2, Stage 3 Alternative, Bottom Fiber

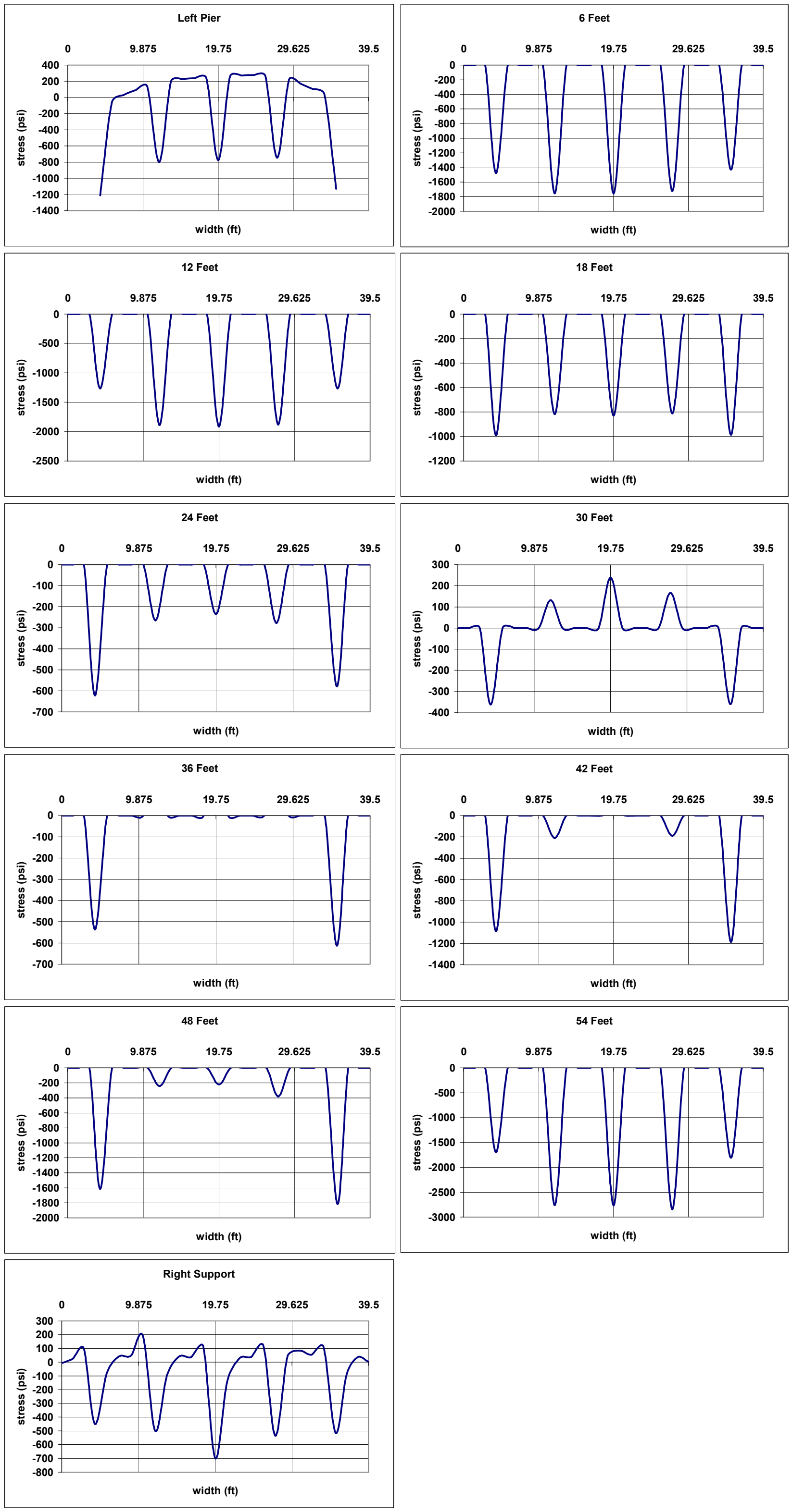

Figure D.43 Bridge I873, Span 3, Stage 3 Alternative, Top Fiber

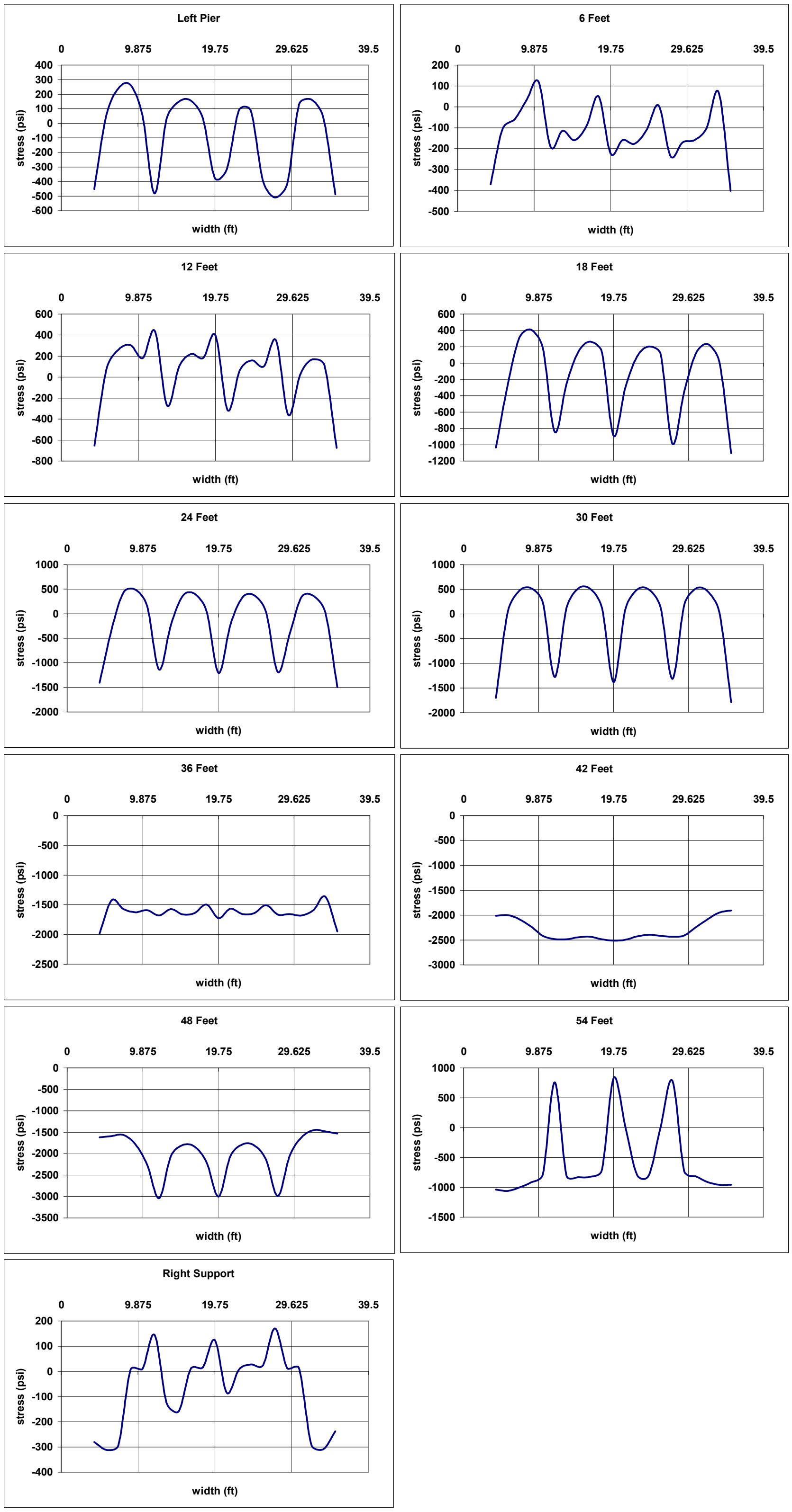

Figure D.44 Bridge I873, Span 3, Stage 3 Alternative, Bottom Fiber

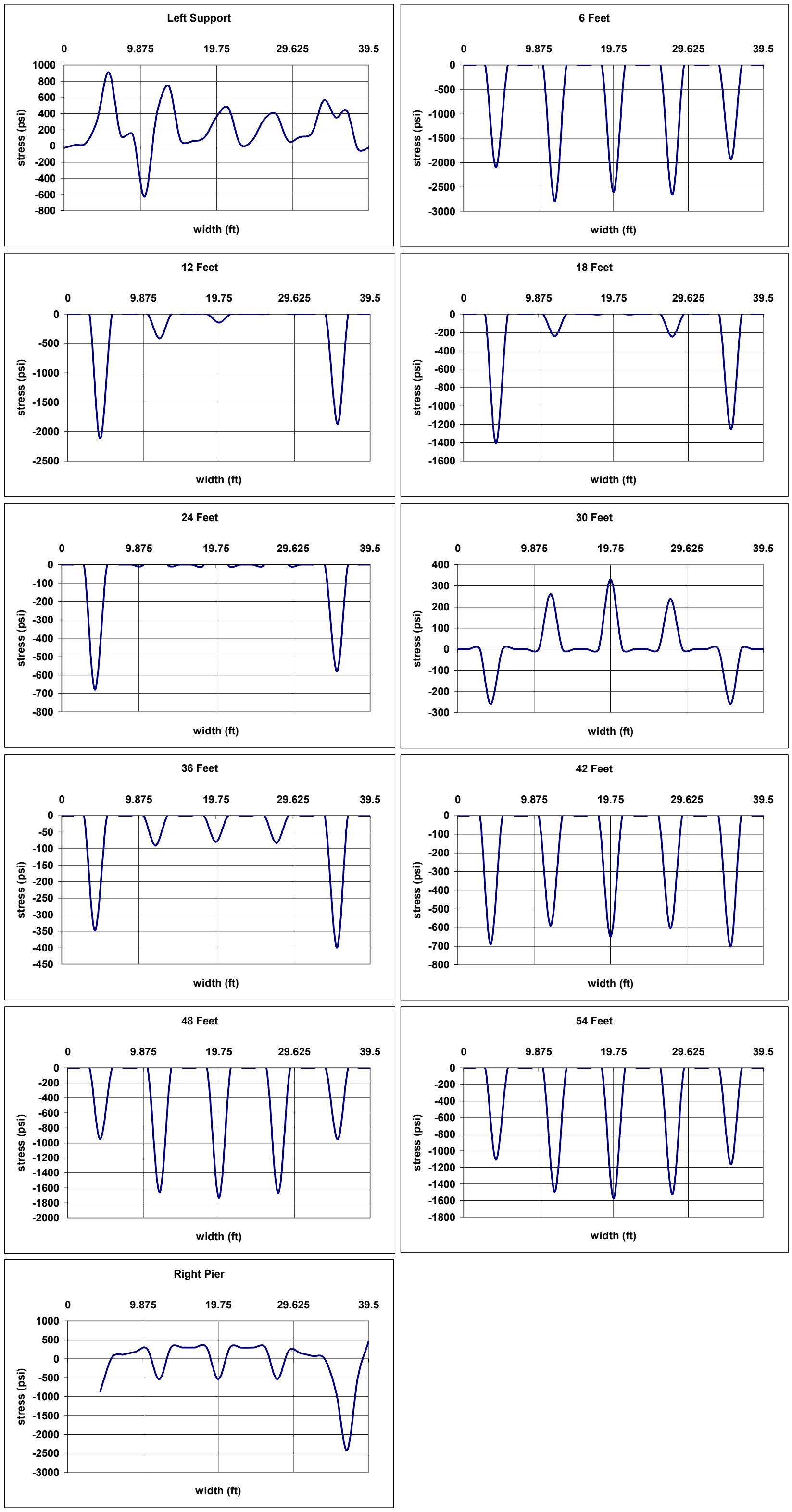

Figure D.45 Bridge I873, Span 1, Stage 4, Top Fiber

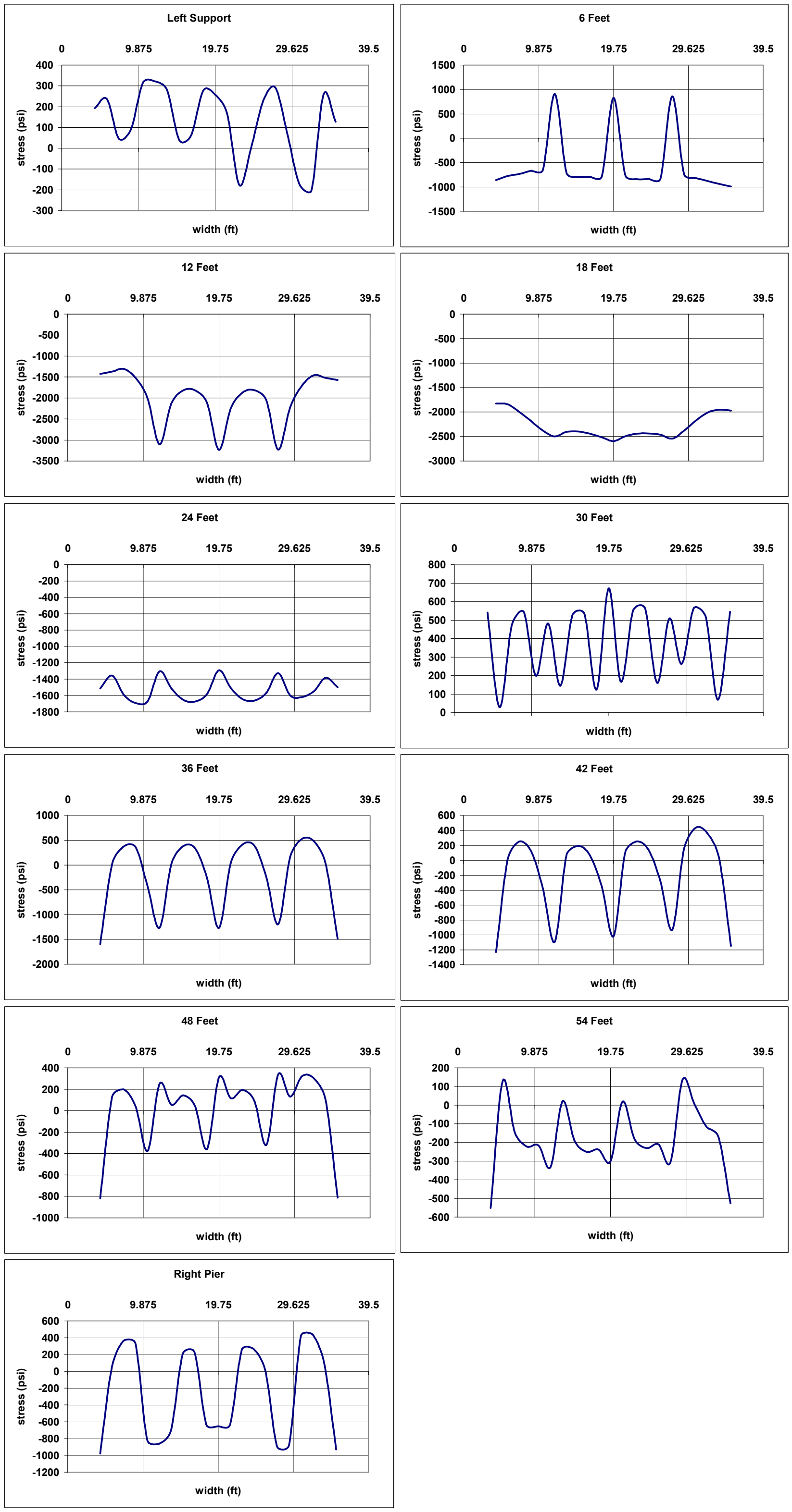

Figure D.46 Bridge I873, Span 1, Stage 4, Bottom Fiber

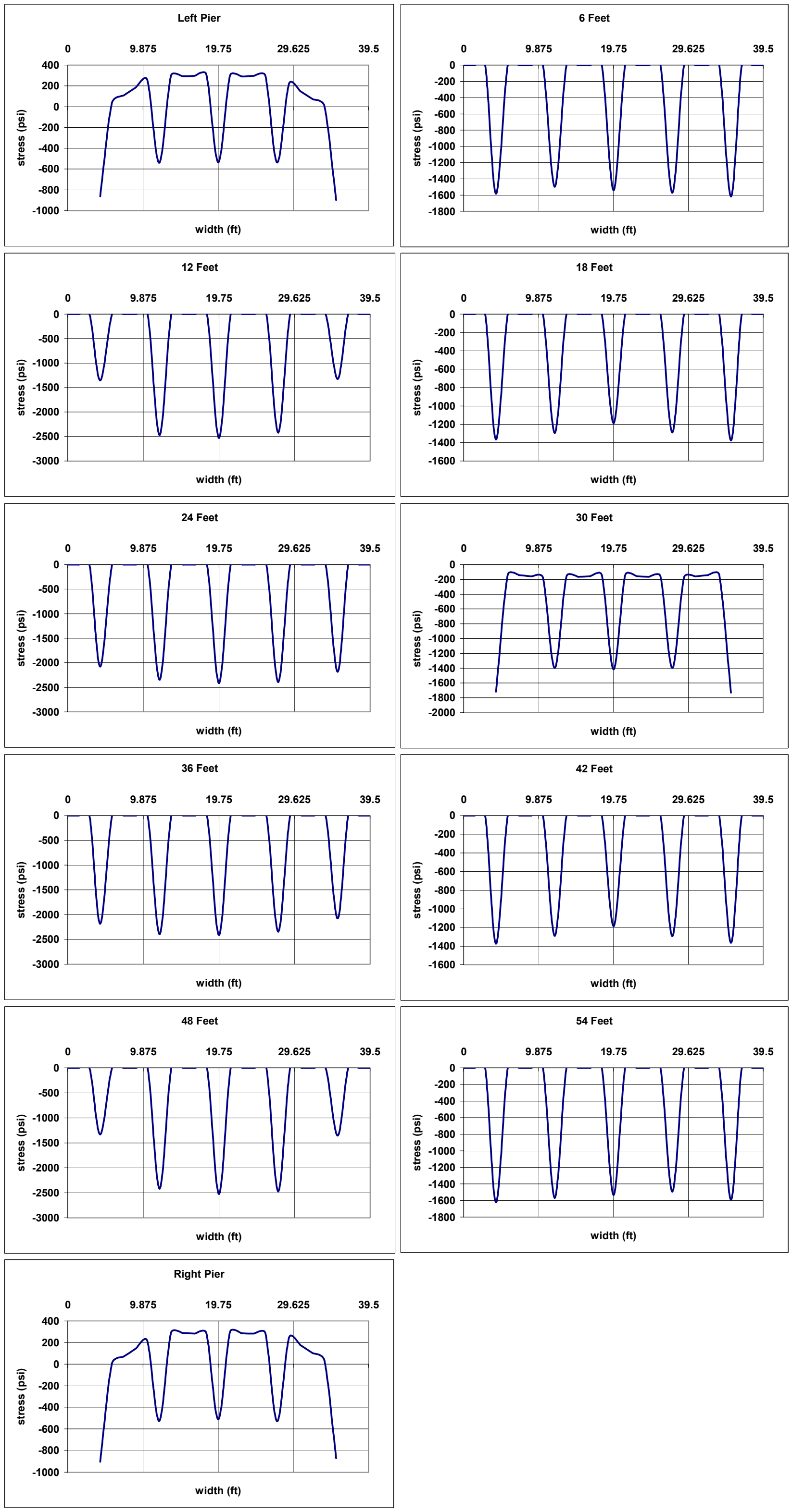

Figure D.47 Bridge I873, Span 2, Stage 4, Top Fiber

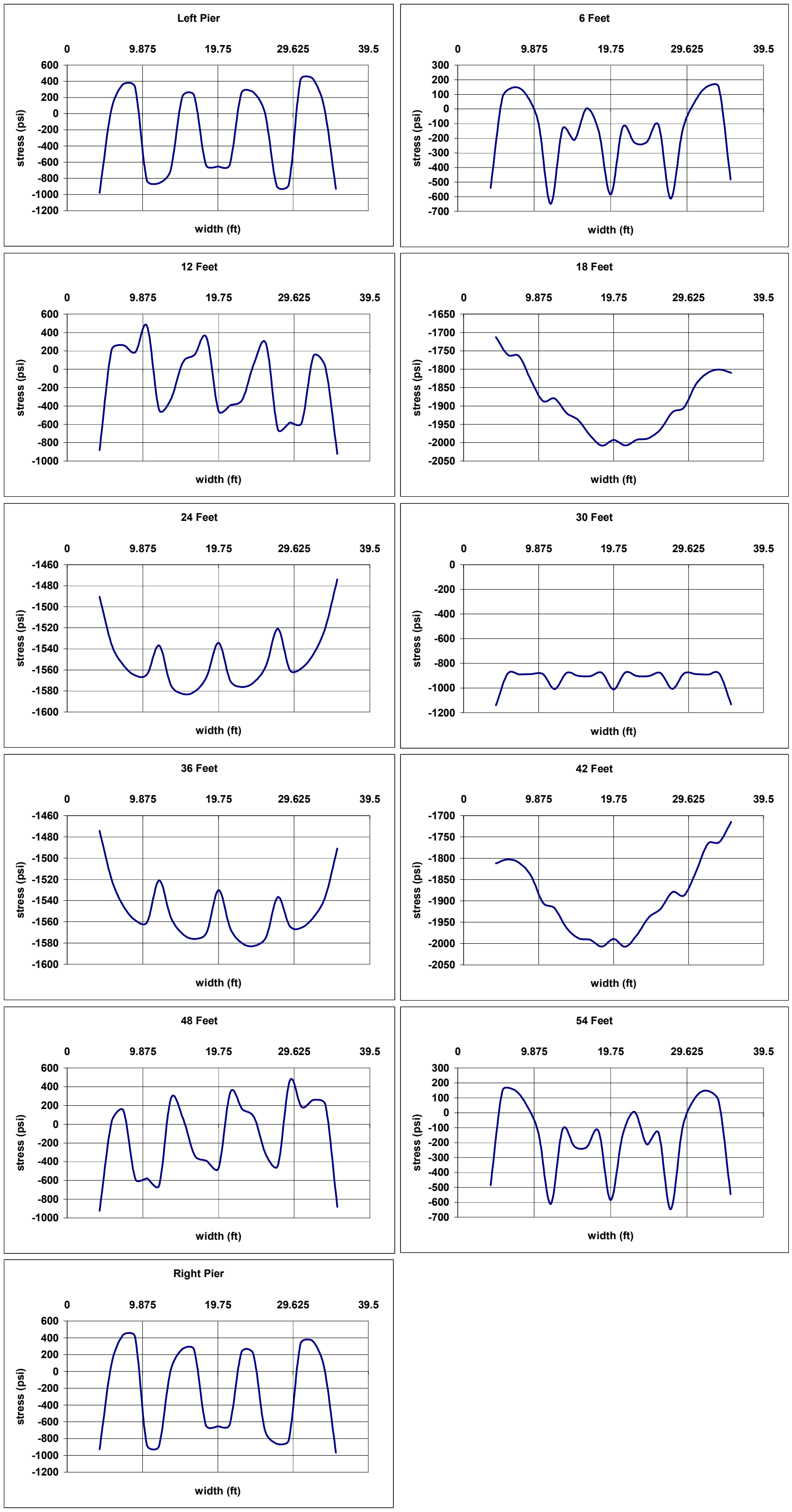

Figure D.48 Bridge I873, Span 2, Stage 4, Bottom Fiber

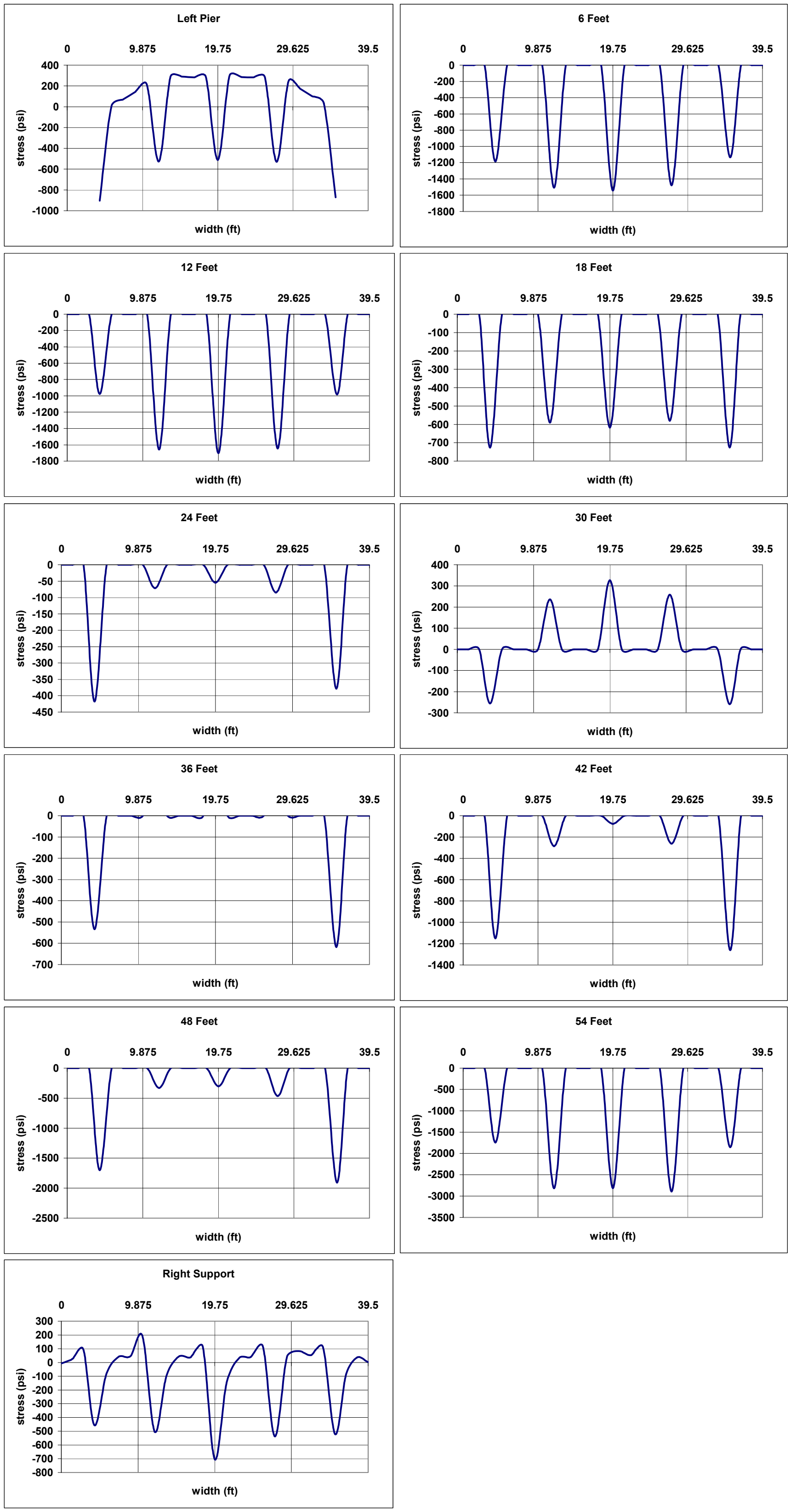

Figure D.49 Bridge I873, Span 3, Stage 4, Top Fiber

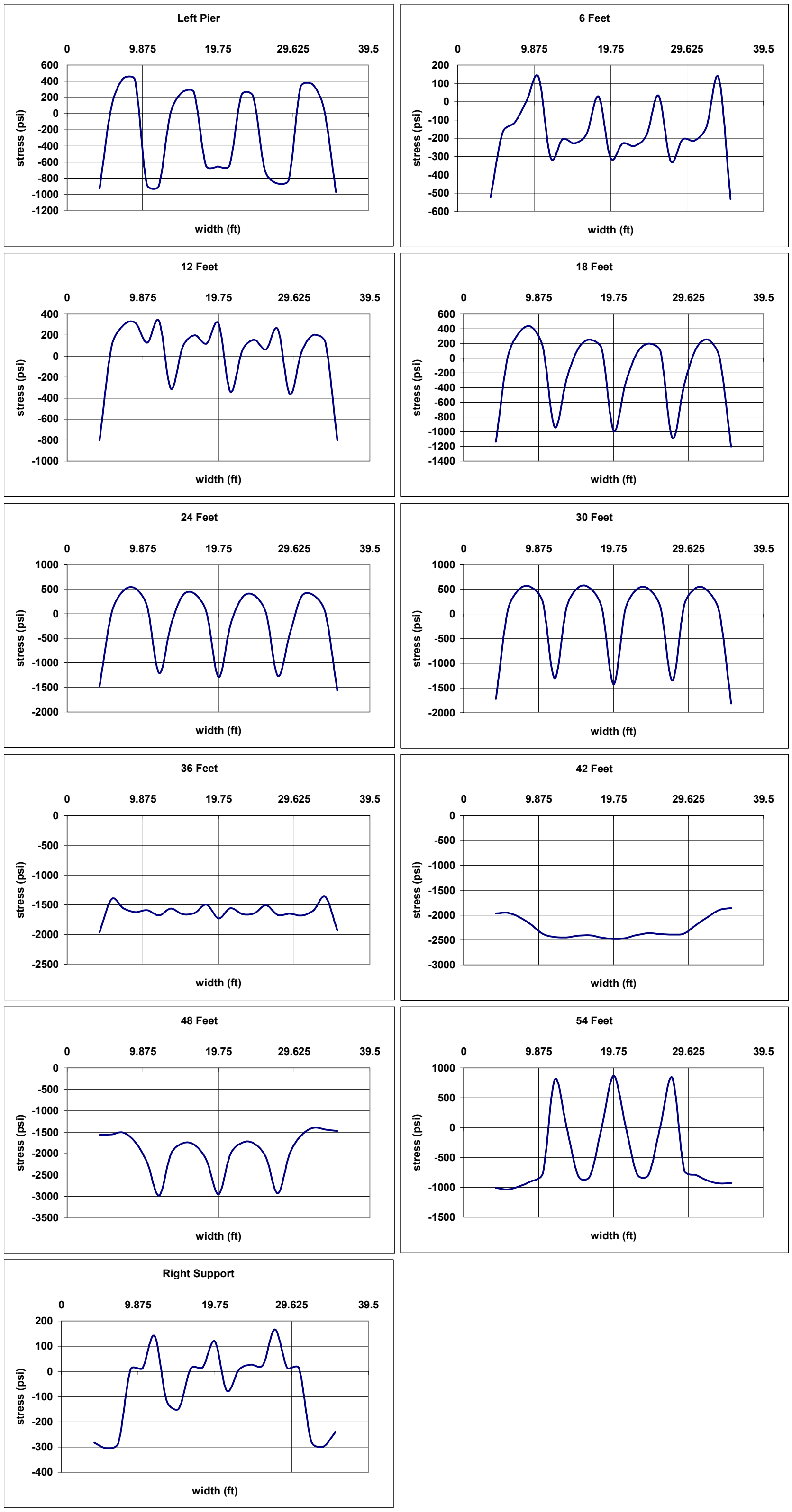

Figure D.50 Bridge I873, Span 3, Stage 4, Bottom Fiber

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