Cap 18 Validation

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1. Preface

Cap18 is a TxDOT specialized structural analysis program using a discrete element model that produces envelopes of maximum bending and shear forces acting on bridge bent caps. HDR uses this software heavily in the bent design process, so validation of this tool is necessary. Since there is no access to the underlying code, validation must be approached differently compared to internal tools. This document will attempt to provide an outline for the process of validating the Cap18 program.

1.1 Cap18 Inputs

This next section will get into the details of what the Cap18 program is. It will try to stay concise. However, there are many inputs to the program, and it is important to list out all of them in order to determine the amount of options available.

The Cap18 program allows the user to provide a number of different inputs. These inputs are provided to the program through a “*.dat” file. This input file is simply a text file that the program can parse and then execute. The file has a specific format that is separated by different “cards”. There are 4 different types of cards.

- Comment Cards
- Header Cards
- Problem Cards
- Table Cards

The specific order of these cards allows the program to know the current card as it steps through each line. Each card is a single line in the input file that contains multiple inputs the program can read. The multiple inputs are separated by the position on the line (ie the first input will be a certain range of characters in the beginning of the line). An input does not have to fill the entire range of characters for that specific input. This range allowance for each input will not be checked directly. Although with the different bents, there will be enough disparity among the inputs to that some level of checking will be done indirectly. A summary of the cards and their list of inputs will now be discussed in more detail to determine the brevity of the check that is needed.

1.1.1 Comment Cards

Comment cards begin with a dollar sign ($) and these lines are for the users own documentation purposes. These cards are ignored by the Cap18 program. No checking is needed here.

1.1.2 Header Cards

Header cards are sort of comment cards, but the Cap18 program needs them to run. These cards only contain general project information that does not affect the results. The same headers will be provided to each run. No checking is needed here.

1.1.3 Problem Cards

Problem cards contain 3 inputs.

- Problem number
- Unit Code
- Description From the problem card inputs, unit code is the only one that will affect results. However only the US Customary unit code will be checked.

1.1.4 Table Cards

1.1.4.1 TABLE 1

Table 1 card contains 9 inputs.

- Print stringer reaction report
- Keep Envelopes from prior problem
- Keep prior Table 2
- Keep prior Table 3
- Keep prior Table 4
- Number of cards for Table 4
- Keep envelopes from random lane
- Print options
- Skew angle

1.1.4.2 TABLE 2

Table 2 has two cards Table2a and Table 2b.

Table 2a has 9 inputs.

- number of slab increments
- increment length
- number of total moving increments
- start station of moving load
- end station of moving load
- step size of moving increments
- analysis option
- dead load factor
- live load factor

Table 2b has 7 inputs.

- overlay factor
- max lanes loaded
- multiple presence factor for 1 lane
- multiple presence factor for 2 lanes
- multiple presence factor for 3 lanes
- multiple presence factor for 4 lanes
- multiple presence factor for 5 lanes

1.1.4.3 TABLE 3

Table 3 has a varied number of inputs depending on the problem. However, they can be classified into 11 different inputs

- number of lanes
- number of stringers
- number of supports
- number of moment points
- station at left lane
- stations at right lane
- station at stringers
- station at supports
- station at moment points
- station at shear points

1.1.4.4 TABLE 4

Table 4 has a varied number of inputs, and they can be classified into 8 different inputs.

- station from
- station to
- cont'd
- bending stiffness of cap
- slab and sidewalk loads
- cap and stringer loads
- moving loads
- overlay loads

To validate Cap18, the program will be run for two different bent configurations. These results will then be compared against one of HDRs validated software programs, LARSA. The different bent configurations will be discussed below. At the end, a summary of the different bent configurations and their inputs into the cap18 program will be shown. The goal is for each input into the Cap18 program to at least have 1 different value across all the different configurations.

1.2 Example 1 - Four Column Bent

Bent Details:

- 6 Tx40 backspan girders
- 6 Tx40 forwardspan girders
- 44' wide bent
- 4 columns spaced at 12'

1.3 Example 2 - Six Column Bent

Bent Details:

- 9 Tx54 backspan girders
- 10 Tx54 forwardspan girders
- 78' wide bent
- 6 columns spaced at 14'

2. Cap18 Verification Summary

2.1 Current Verified Inputs

Below is a table showing the total inputs to the cap18 program, and the respective inputs for each example problem run. The “Checked” column values are an “X” when the two inputs between the two examples are different. The idea is that different inputs between the two examples ensures the input was checked for multiple different values and is thus a verified input (depending on the results of the comparison). When an “X” is not present, a comment is added to explain the reason why there were not different inputs provided between the two example problems.

Some inputs were not checked in the cap18 program. The inputs checked account for 95% of the use cases for the program. Additional time and effort is needed to verify the inputs with the comment “Not a feature used by our program”. Further verification can be done if or when needed.

Table 1. Cap18 Verification: Current Verified Inputs

Card	Inputs	Example 1	Example 2	Checked	Comments
Header 1	File No.	-	-	-	Does not affect analysis
Header 1	County	-	-	-	Does not affect analysis
Header 1	Hwy No.	-	-	-	Does not affect analysis
Header 1	PD/IPE	-	-	-	Does not affect analysis
Header 1	CSJ	-	-	-	Does not affect analysis
Header 1	Coded by	CAM	CAM	-	Does not affect analysis
Header 1	date	2024-10-18	2024-10-18	-	Does not affect analysis
Header 1	comments	-	-	-	Does not affect analysis
Header 2	structure description	Bent Cap Analysis For Cap18 Validation: Four Column Bent	Bent Cap Analysis For Cap18 Validation: Six Column Bent	X	-
Problem Card	Problem Number	1-LB	1-LB	-	-
Problem Card	System Unit Code	E	E	-	Will not use Metric Units
Problem Card	Problem Description	Single problem for bent cap - same bm spa back and fwd	Single problem for bent cap - same bm spa back and fwd	-	-
Table 1	Stringer reaction report option	-	-	-	Not a feature used by our program.
Table 1	Keep prior envelopes option	-	-	-	Not a feature used by our program.
Table 1	Keep prior Table 2	-	1	X	-
Table 1	Keep prior Table 3	-	-	-	Not a feature used by our program.
Table 1	Keep prior Table 4	-	-	-	Not a feature used by our program.
Table 1	Number of Table 4 cards	17	41	X	-
Table 1	Envelope options	-	-	-	Not a feature used by our program.
Table 1	Print options	-	-	-	Not a feature used by our program.

Table 1	Skew Angle	0	0	-	The programs we use do the skew conversions (Example 2 has a skew)
Table 2a	Number of Increments	88	157	X	-
Table 2a	Increment Length	0.5	0.5	-	Program we use encourage and warn to use a 0.5ft increment
Table 2a	Movable Load increment Number	20	23	X	-
Table 2a	Movable Load Start Sta	2	2	-	-
Table 2a	Movable Load Stop Sta	66	131	X	-
Table 2a	Movable Load Step Size	1	1	-	Keep at most refined option.
Table 2a	Analysis Option	3	3	-	Option 3 performs both working stress and load factor designs. Will keep as both
Table 2a	Dead Load Factor	1.25	1.25	-	Will keep load factors as AASHTO standards
Table 2a	Live Load Factor	1.75	1.75	-	Will keep load factors as AASHTO standards
Table 2b	Overlay Load Factor	1.5	1.5	-	Will keep load factors as AASHTO standards
Table 2b	Max Number of Lane Loads	3	5	X	-
Table 2b	Multiple Presence Factor 1 Lane	1.2	1.2	-	Will keep as AASHTO standards
Table 2b	Multiple Presence Factor 2 Lane	1	1	-	Will keep as AASHTO standards
Table 2b	Multiple Presence Factor 3 Lane	0.85	0.85	-	Will keep as AASHTO standards
Table 2b	Multiple Presence Factor 4 Lane	-	0.65	X	-
Table 2b	Multiple Presence Factor 5 Lane	-	0.65	X	-
Table 3	Number of Control Points - Lanes	3	5	X	-
Table 3	Number of Control Points - Stringers	6	9	X	-
Table 3	Number of Control Points - Supports	4	6	X	-
Table 3	Number of Control Points - Moments	10	14	X	-
Table 3	Number of Control Points - Shears	8	12	X	-
Table 3	Stations at left of lane	2, 30, 58	2, 32, 63, 93, 124	X	-

Table 3	Stations at right of lane	30, 58, 86	32, 63, 93, 124, 154	X	-
Table 3	Stations at stringers	4, 20, 36, 52, 68, 84	6, 24, 42, 59, 77, 95, 113, 131, 149	X	-
Table 3	Stations at supports	8, 32, 56, 80	9, 37, 65, 93, 121, 149	X	-
Table 3	Stations at design control points for moments	4, 8, 20, 32, 36, 52, 56, 68, 80, 84	6, 9, 24, 37, 42, 59, 65, 77, 93, 95, 113, 121, 131, 149	X	-
Table 3	Stations at design control points for shears	6, 10, 30, 34, 54, 58, 78, 82	4, 11, 35, 39, 63, 67, 91, 97, 119, 123, 147, 151	X	-
Table 4	From Sta	multiple different values	multiple different values	X	-
Table 4	To Sta	multiple different values	multiple different values	X	-
Table 4	Continue to next card?	-	-	-	functionality we do not use
Table 4	Bending stiffness of cap	6.93347e6	1.18282e7	X	-
Table 4	Slab and sidewalk loads	multiple different values	multiple different values	X	-
Table 4	Cap and stringer loads	multiple different values	multiple different values	X	-
Table 4	Moving loads	multiple different values	multiple different values	X	-
Table 4	Overlay loads	-	multiple different values	X	-

2.2 Summary of the Results

The Cap18 program was found to adequatley model the two example problems. The results between the two programs was found to be very similar. Most of the differences in the stresses found were due to the way cap18 modeled the point loads compared to how the point loads were defined in the larsa model. The point loads were modeled in larsa as true point loads, while cap18 provided a more realistic load that was spread out to reflect the bottom of a beam. The other discrepency was due to the limitation in how the live load was defined in larsa. Since, the larsa model was treating the live load as a truck or trucks moving along a span (instead of a transverse movement within defined lanes), there were no lane definitions to keep trucks within their respective lanes. The trucks were allowed to move “as one” with no gap in between them. Larsa also did not seem to capture different maximum values when spanmarks were added. This is probably due to the live load being on the slab elements when the cap elements needed to be maximized. While these differences could be seen between the two models, the results were still relatively close, and when there were greater discrepencies, cap18 had the higher stresses.

3. Example 1 - Four Column Bent

3.1 Bent Summary

Example 1 was run for both Larsa and Cap18. Below is a short summary of the bent details.

Bent Details:

- 6 Tx40 backspan girders
- 6 Tx40 forwardspan girders
- 44’ wide bent
- 4 columns spaced at 12’

3.1.1 Back Span

The figure below shows the beam spacing for the backspan girders. Since Cap18 works in half-foot increments, the beam spacing was rounded to the nearest increments. Both Cap18 and Larsa have the same spacing for the beams.

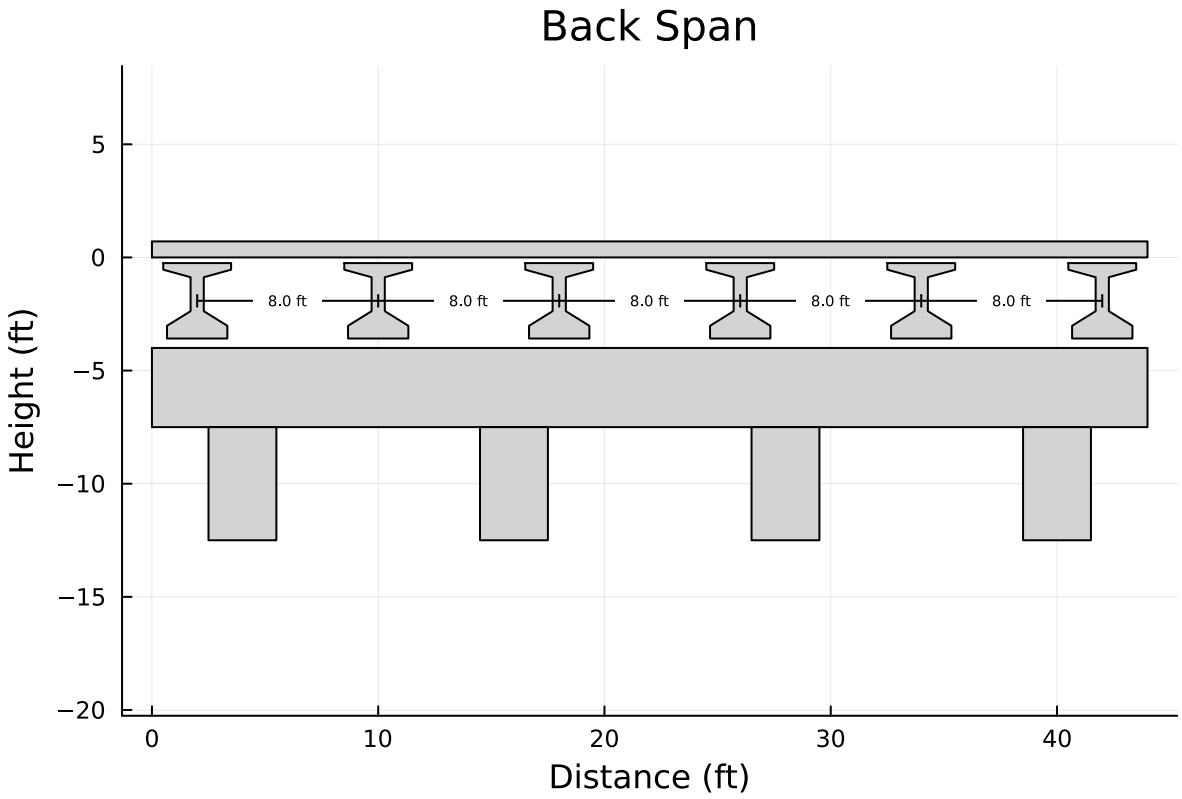

Figure 3.1: Section View of Back Span

3.1.2 Forward Span

The figure below shows the beam spacing for the forwardspan girders.

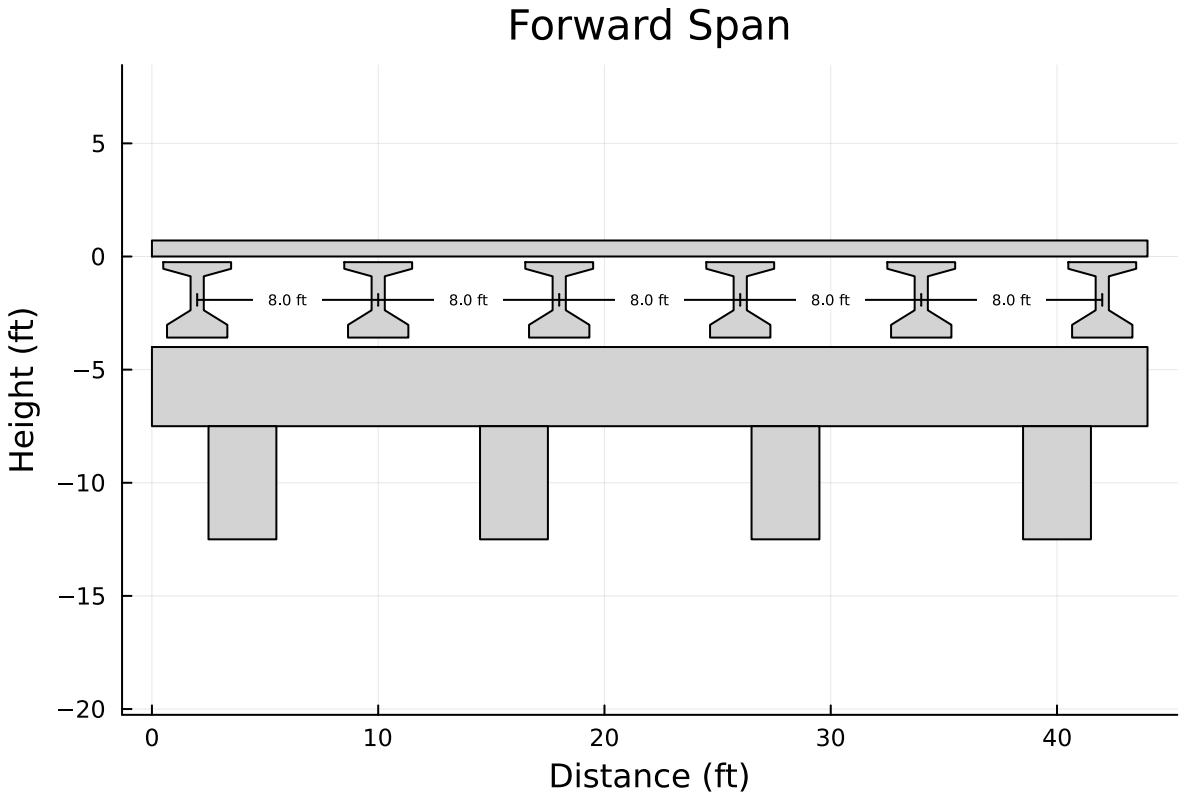

Figure 3.2: Section View of Forward Span

3.2 Cap 18

A Cap18 input file was created and ran for the above bent. The output file was then parsed for the dead load, working stress, and load factor cases. The summary of the findings are discussed below.

3.2.1 SRV

3.2.1.1 DEAD LOAD RESULTS (SRV)

The dead load results were plotted on top of the bent to get a better visual understanding of the results. Based on the DL shear and moment diagrams below, the Cap18 results look to align well with the bent. Sharp changes in shear happen in areas with either a column or a beam, and negative moments are maximized over the columns. This indicates to some degree that the expected behavior of the stresses within the cap is being captured by the Cap18 program. A more detailed comparison with Larsa results will help determine if the magnitudes of these stresses are correct.

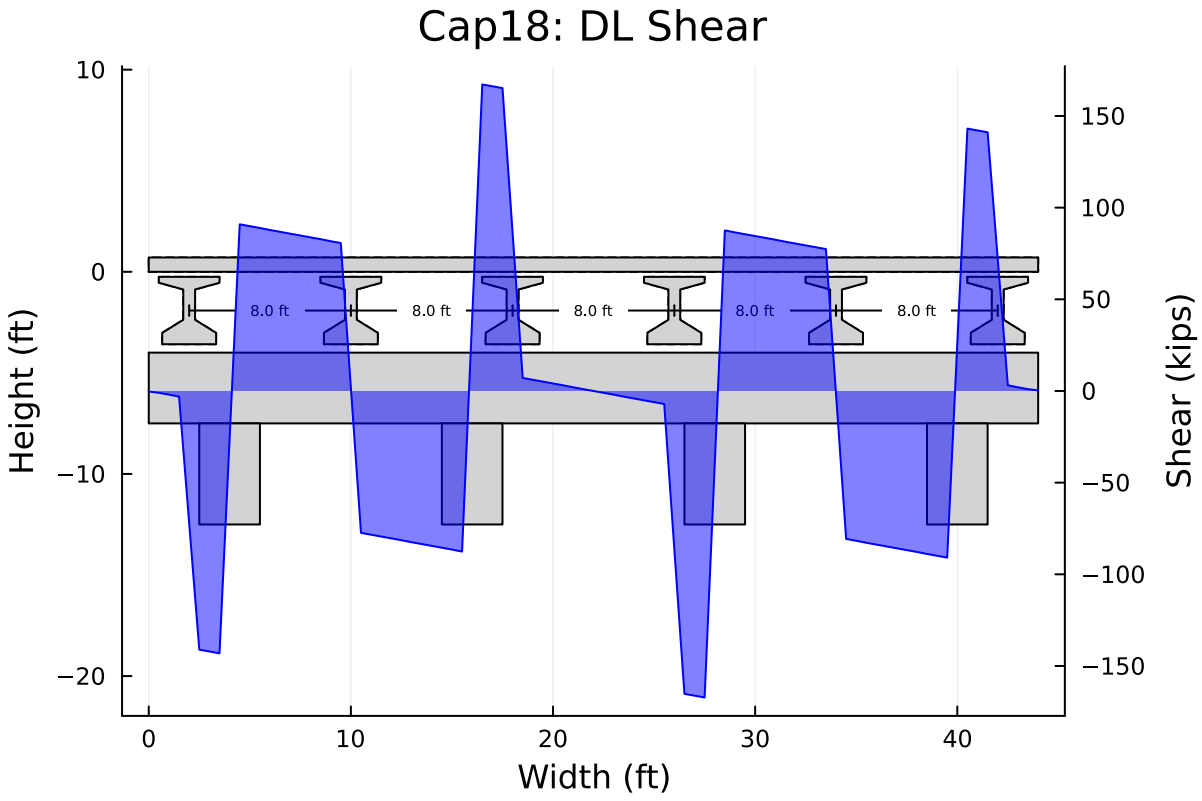

Figure 3.3: Cap18: DL Shear Diagram

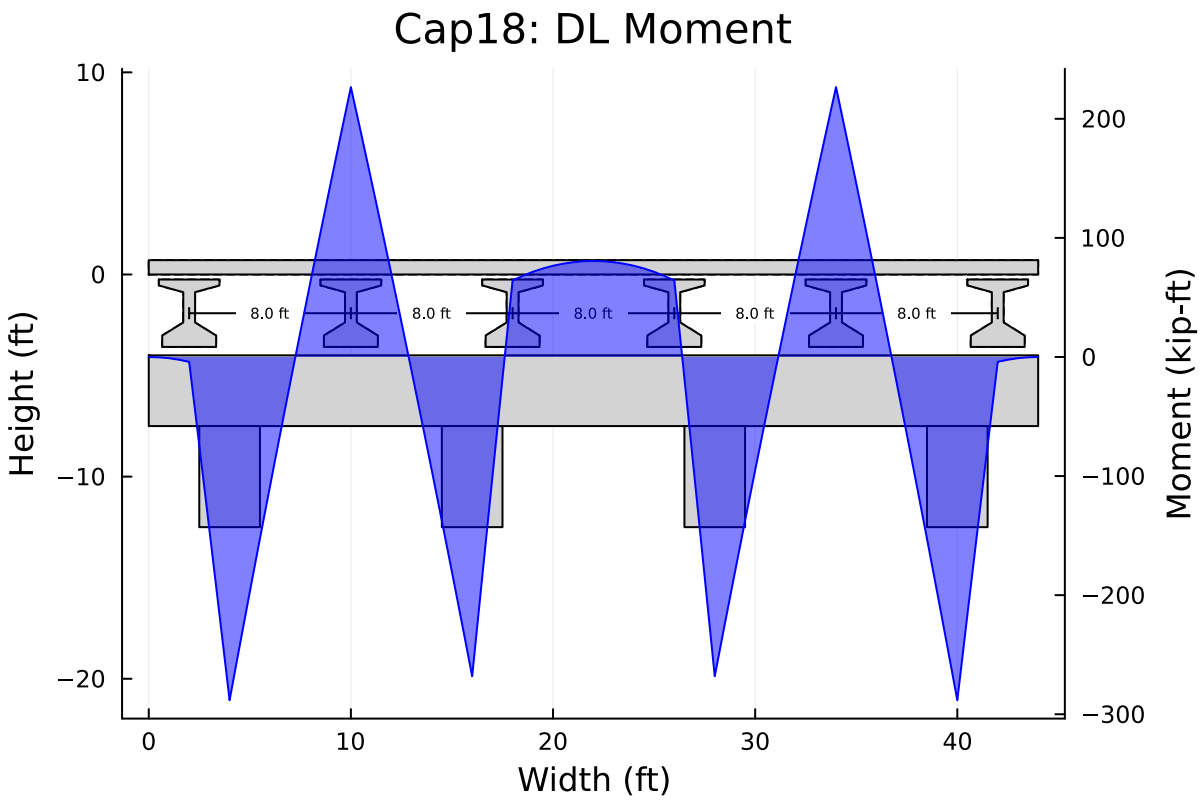

Figure 3.4: Cap18: DL Moment Diagram

3.2.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

The working stress results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Larsa is needed.

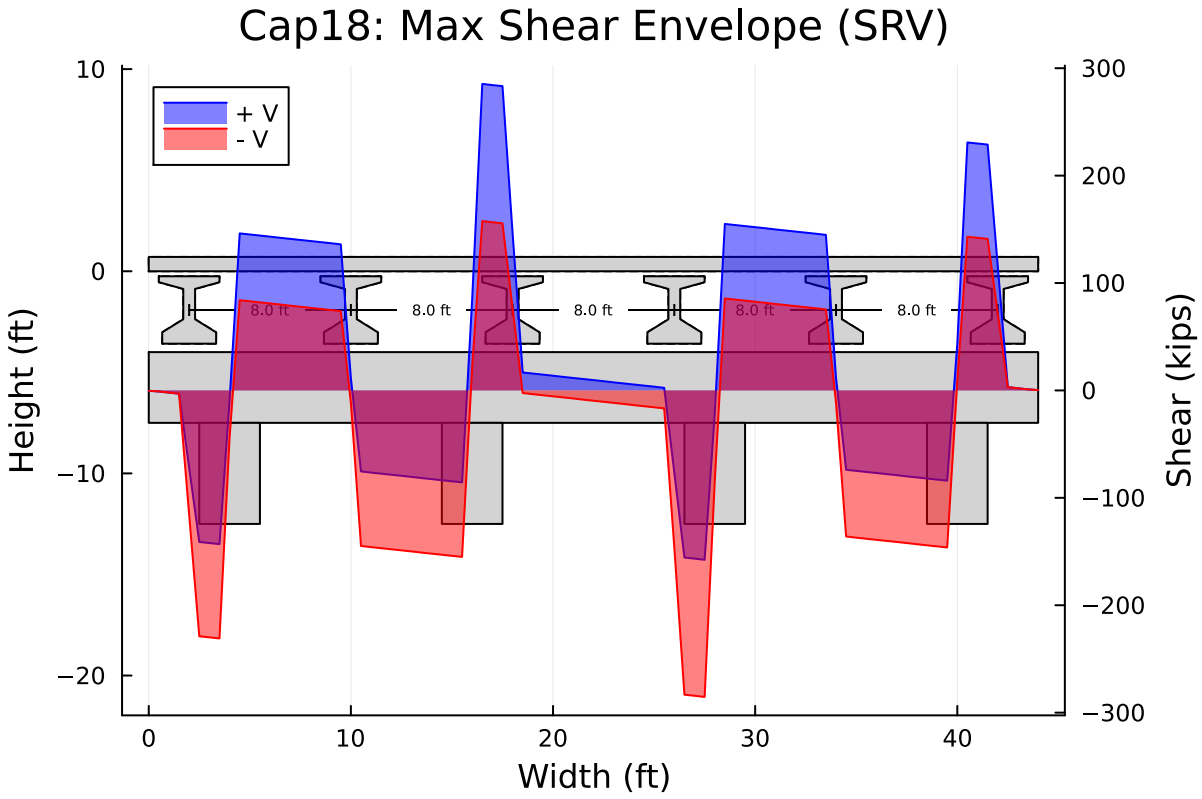

Figure 3.5: Cap18: Service Shear Envelope Diagram

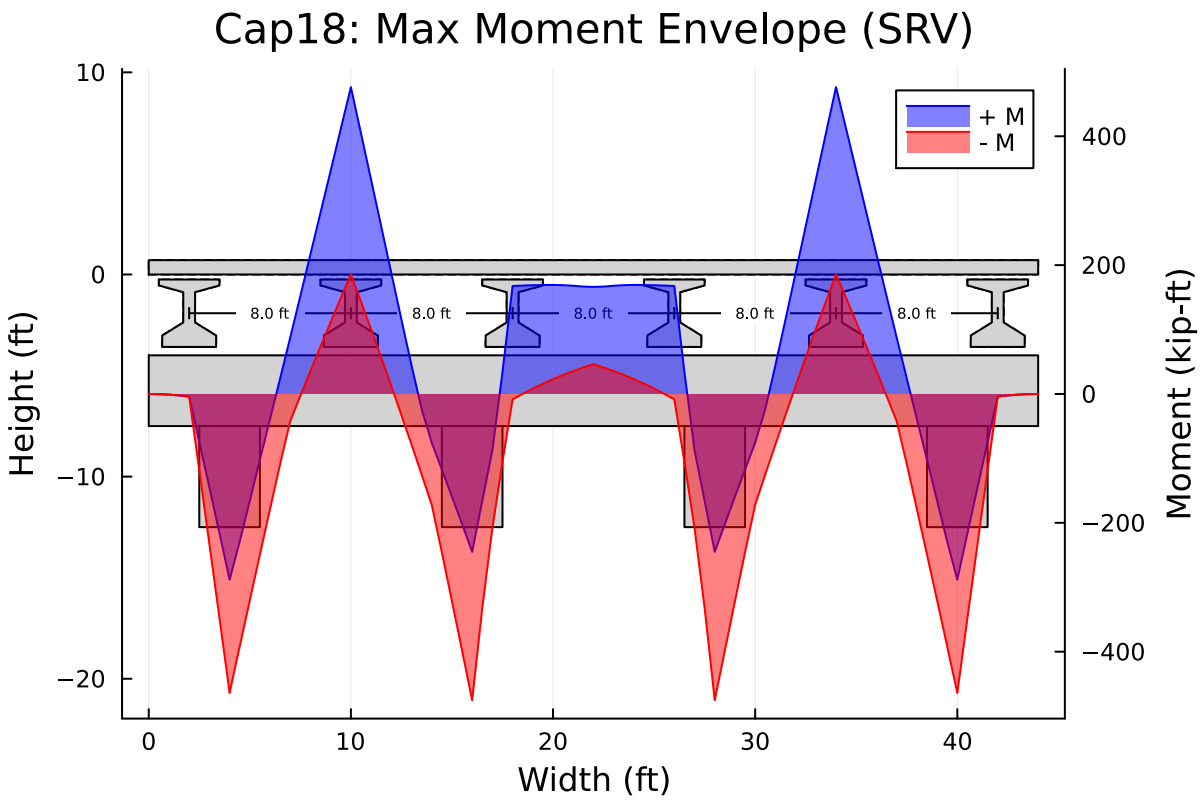

Figure 3.6: Cap18: Service Moment Envelope Diagram

3.2.1.3 MAXIMUM SUPPORT REACTIONS (SRV)

The maximum and minimum support reactions for the working stress case are listed in the table below.

Table 2. Cap18: Service Reactions

Station	Distance	Max Reactions	Min Reactions
8	4.0 ft	376.5 kip	229.2 kip
32	16.0 ft	441.0 kip	245.3 kip
56	28.0 ft	441.0 kip	245.3 kip
80	40.0 ft	376.5 kip	229.2 kip

3.2.2 STR

3.2.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The load factor results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Larsa is needed.

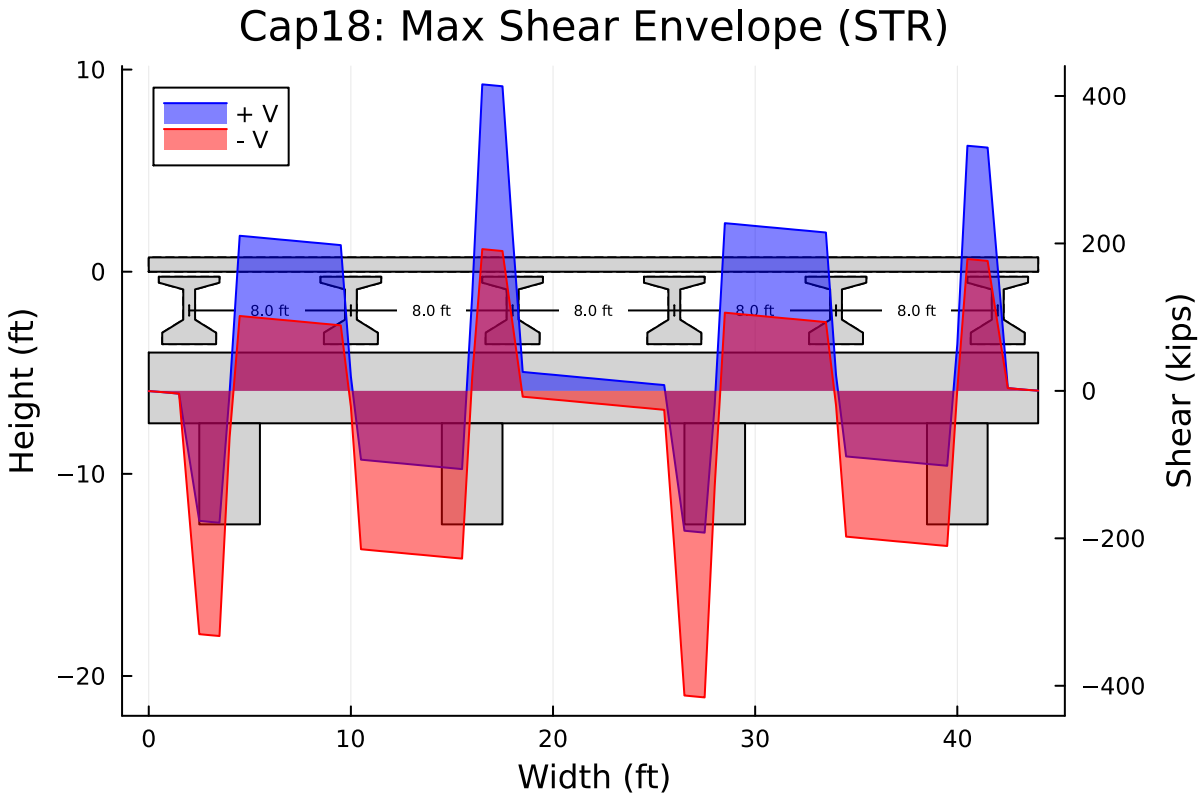

Figure 3.7: Cap18: Strength Shear Envelope Diagram

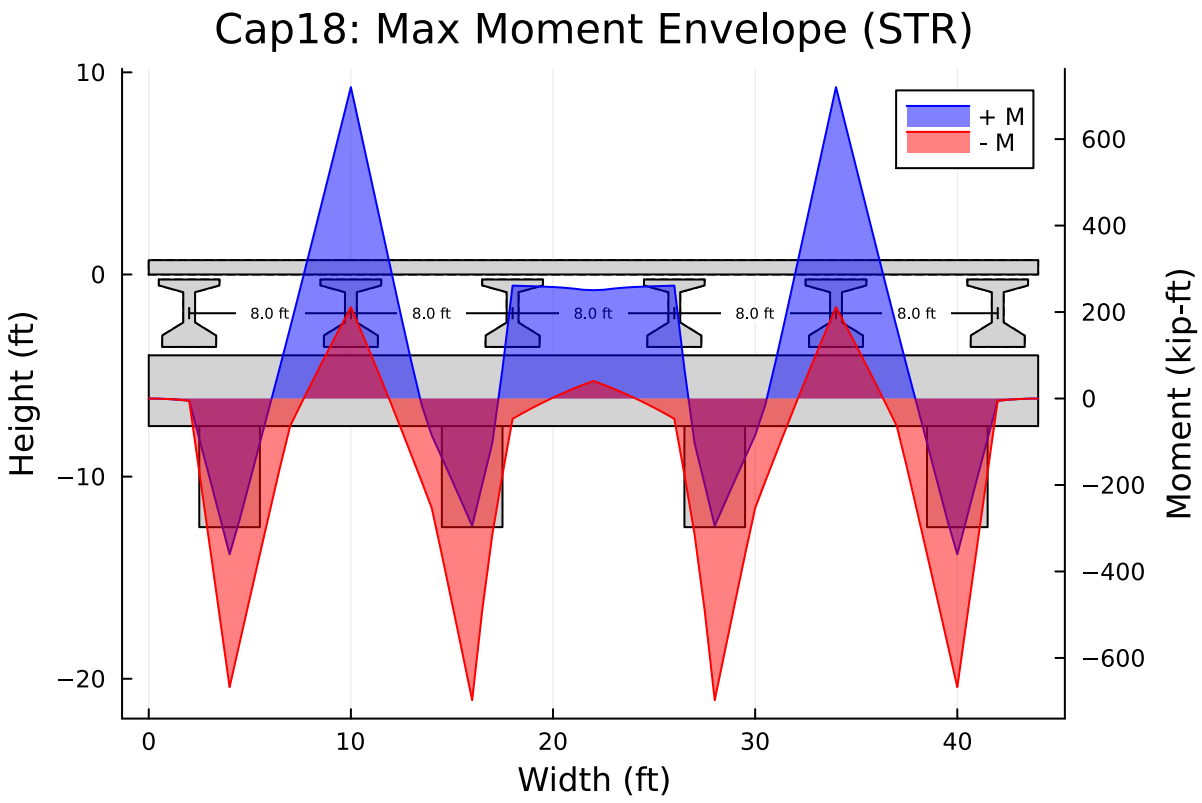

Figure 3.8: Cap18: Strength Moment Envelope Diagram

3.2.2.2 MAXIMUM SUPPORT REACTIONS (STR)

The maximum and minimum support reactions for the load factor case are listed in the table below.

Table 3. Cap18: Strength Reactions

Station	Distance	Max Reactions	Min Reactions
8	4.0 ft	540.9 kip	283.0 kip
32	16.0 ft	643.3 kip	300.9 kip
56	28.0 ft	643.3 kip	300.9 kip
80	40.0 ft	540.9 kip	283.0 kip

3.3 Larsa Results

A Larsa model was created and ran for the above bent. The loads were extracted for the dead load, working stress, and load factor cases. The summary of the findings are discussed below.

3.3.1 SRV

3.3.1.1 DEAD LOAD RESULTS (SRV)

The dead load results were plotted on top of the bent to get a better visual understanding of the results. Based on the DL shear and moment diagrams below, the Larsa results look to align well with the bent. A more detailed comparison with the Cap18 results will help determine if the magnitudes of the stresses calculated from the Cap18 program are correct.

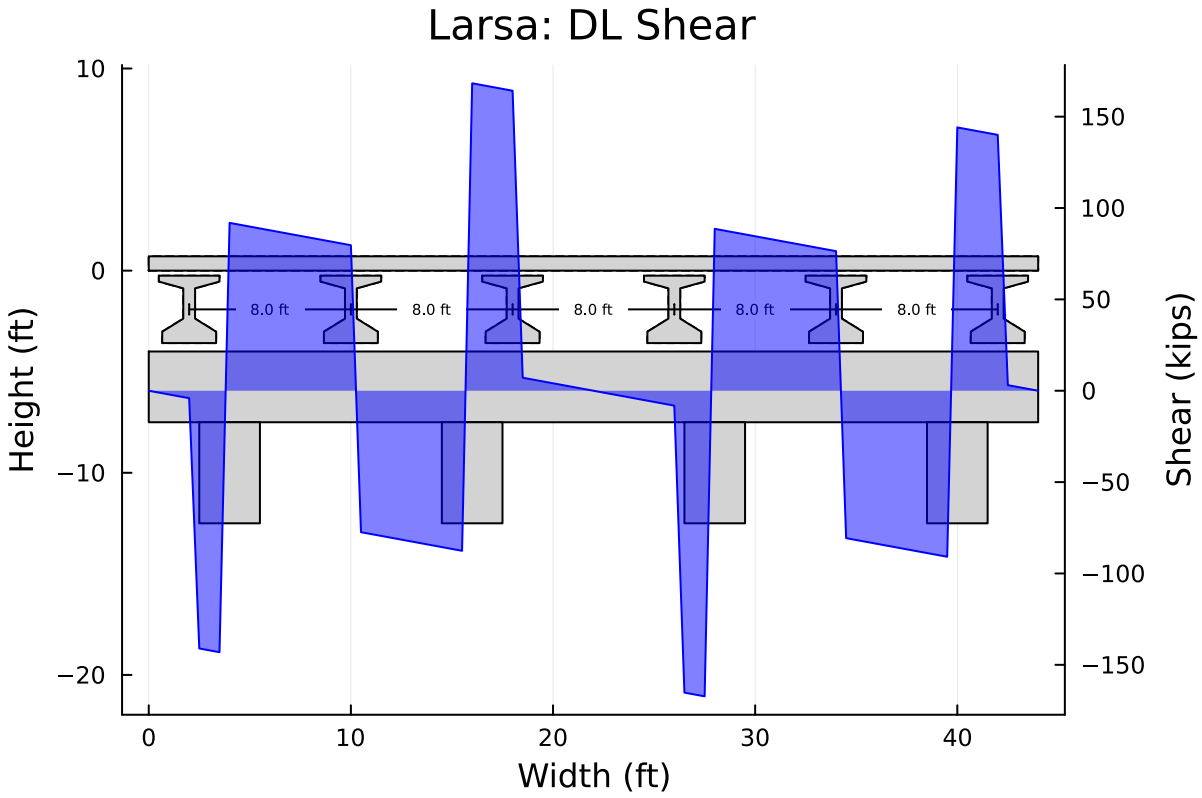

Figure 3.9: LARSA: DL Shear Diagram

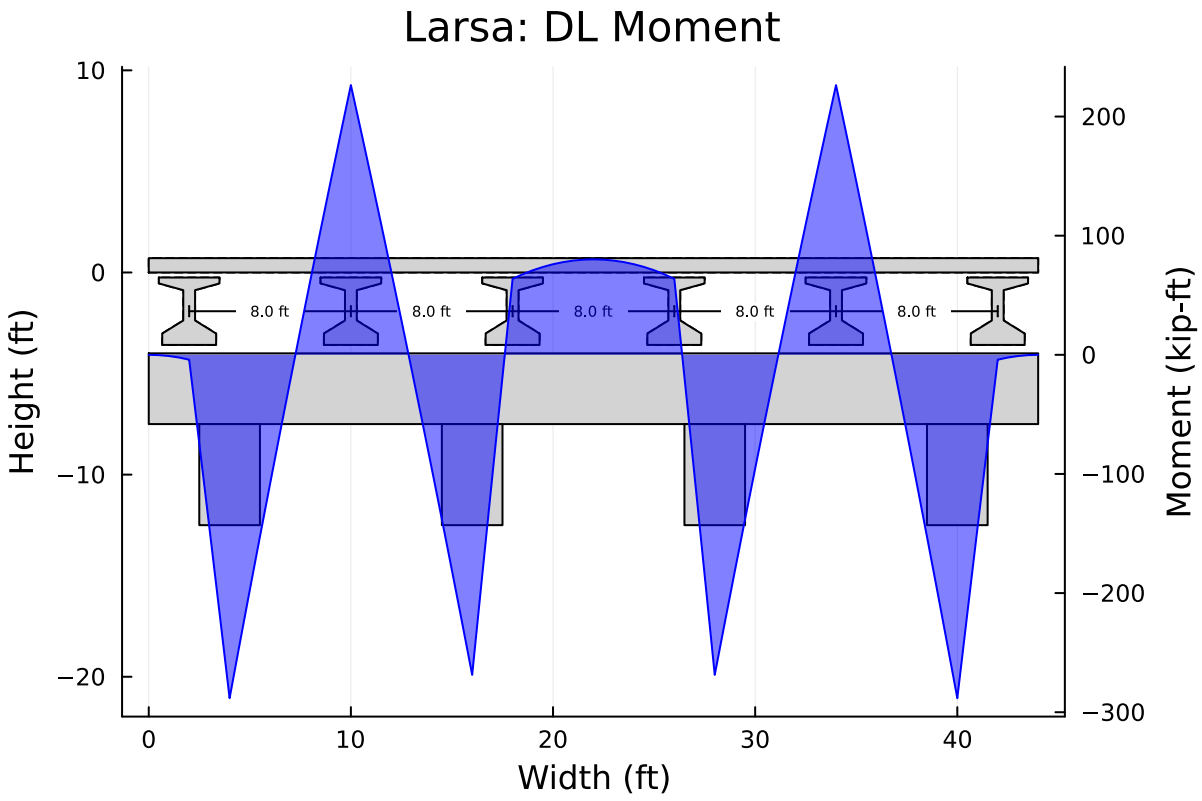

Figure 3.10: LARSA: DL Moment Diagram

3.3.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

The working stress results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Cap18 is needed.

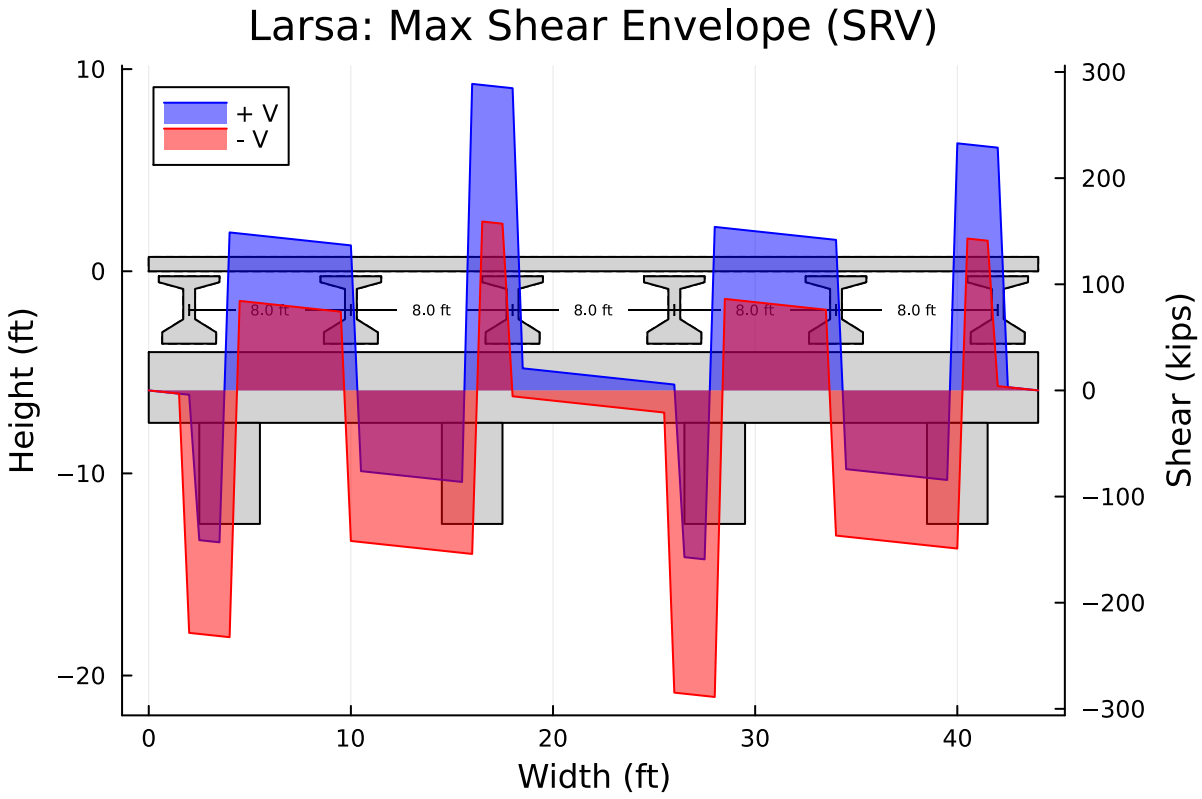

Figure 3.11: LARSA: Service Shear Envelope Diagram

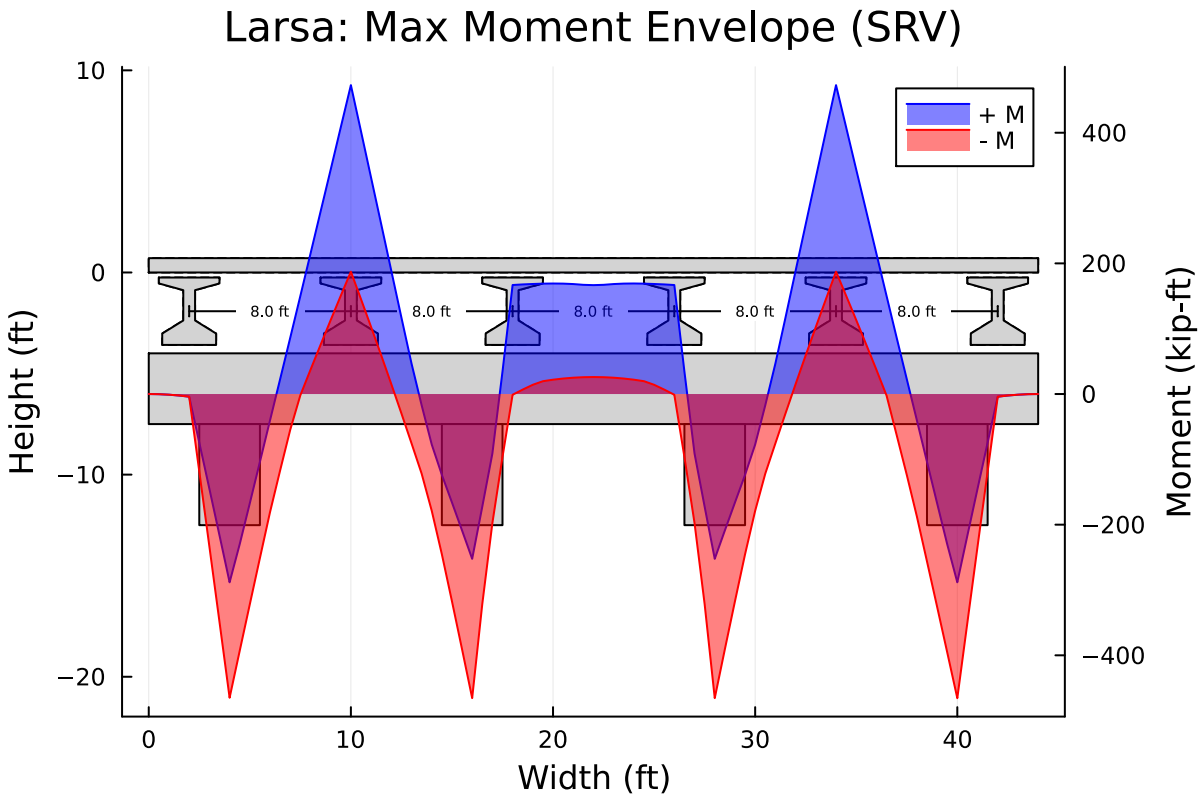

Figure 3.12: LARSA: Service Moment Envelope Diagram

3.3.1.3 MAXIMUM SUPPORT REACTIONS (SRV)

The maximum and minimum support reactions for the working stress case are listed in the table below.

Table 4. LARSA: Service Reactions

Station	Distance	Max Reactions	Min Reactions
8	4.0 ft	376.619 kip	229.487 kip
32	16.0 ft	439.42 kip	247.414 kip
56	28.0 ft	439.42 kip	247.414 kip
80	40.0 ft	376.577 kip	229.49 kip

3.3.2 STR

3.3.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The load factor results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Cap18 is needed.

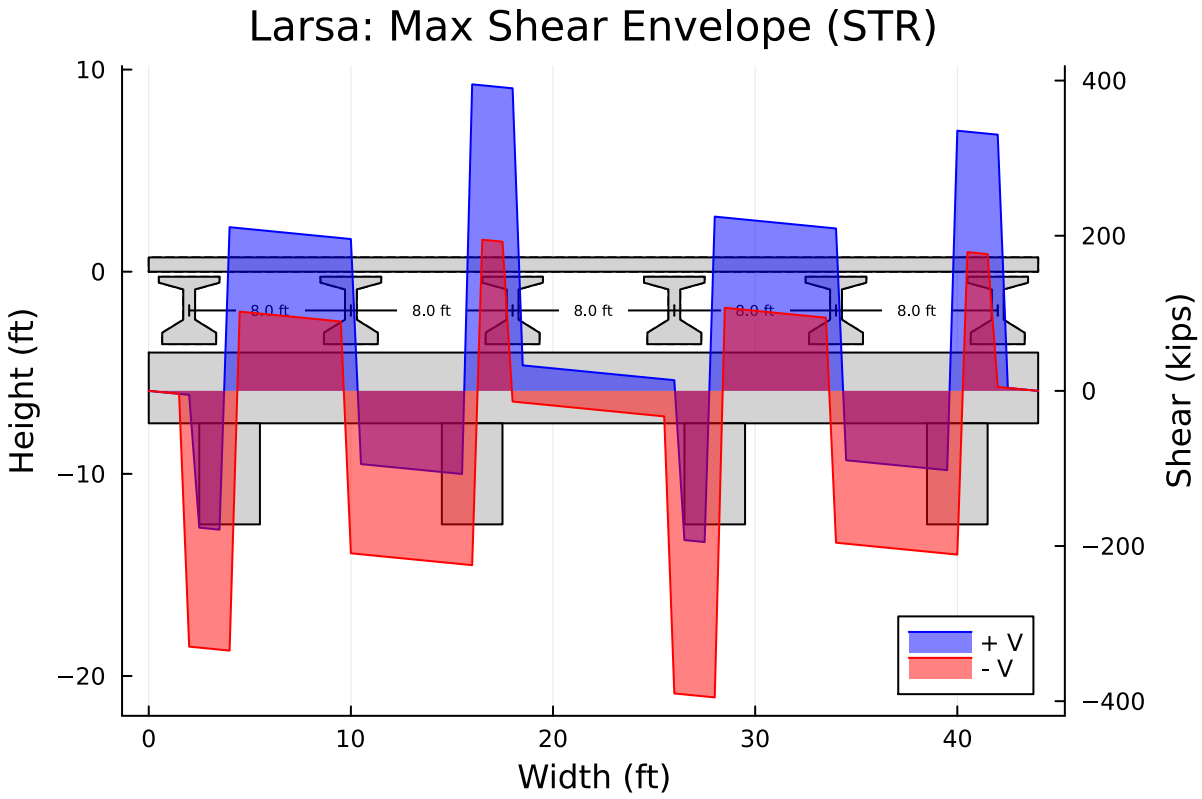

Figure 3.13: LARSA: Strength Shear Envelope Diagram

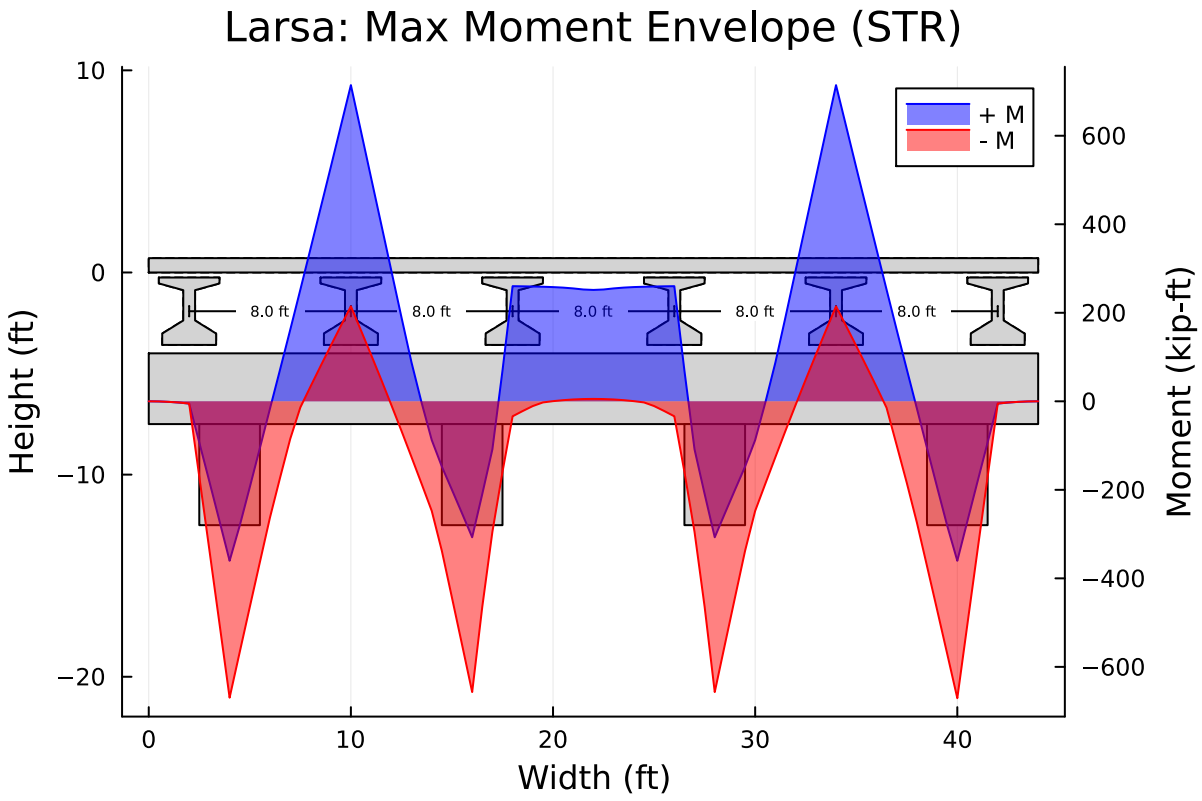

Figure 3.14: LARSA: Strength Moment Envelope Diagram

3.3.2.2 MAXIMUM SUPPORT REACTIONS (STR)

The maximum and minimum support reactions for the load factor case are listed in the table below.

Table 5. LARSA: Strength Reactions

Station	Distance	Max Reactions	Min Reactions
8	4.0 ft	541.086 kip	283.606 kip
32	16.0 ft	604.078 kip	304.531 kip
56	28.0 ft	604.078 kip	304.531 kip
80	40.0 ft	541.013 kip	283.611 kip

3.4 Comparison

Below is a comparison of the Cap18 and Larsa results. Stresses were found to be fairly similar between the different programs. The main differences are in the shear stresses. Cap18 seems to have a more gradual change in shear compared to Larsa. This is most likely due to the way Cap18 defines the point loads in the program. This gradual vs more sharp change in shear does not seem to affect the moment diagram in a significant way. Moment diagram stresses do show some differences and will be discussed in more detail below.

Important Plot Information

The comparison plots for the shear and moment diagrams are shown below for all the different load cases. The Cap18 results are shown in a blue line and the larsa results are shown in a red line. The red line will only really be visible when the larsa results are greater in magnitude than the cap18 results. The thickness of the red or blue line shows how much greater in magnitdue the respective result was. The absolute difference between larsa and cap18 is show in yellow. Any positive yellow results indicate that larsa was greater in magnitude. Data labels are also visible for the moment diagrams at the local extrema. Text in blue indicates that Cap18 was greater in magnitude, while red text indicates larsa results were greater in magnitude.

3.4.1 SRV

3.4.1.1 DEAD LOAD RESULTS (SRV)

The figures below compare the DL results between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment and shears, the results are within 1%.

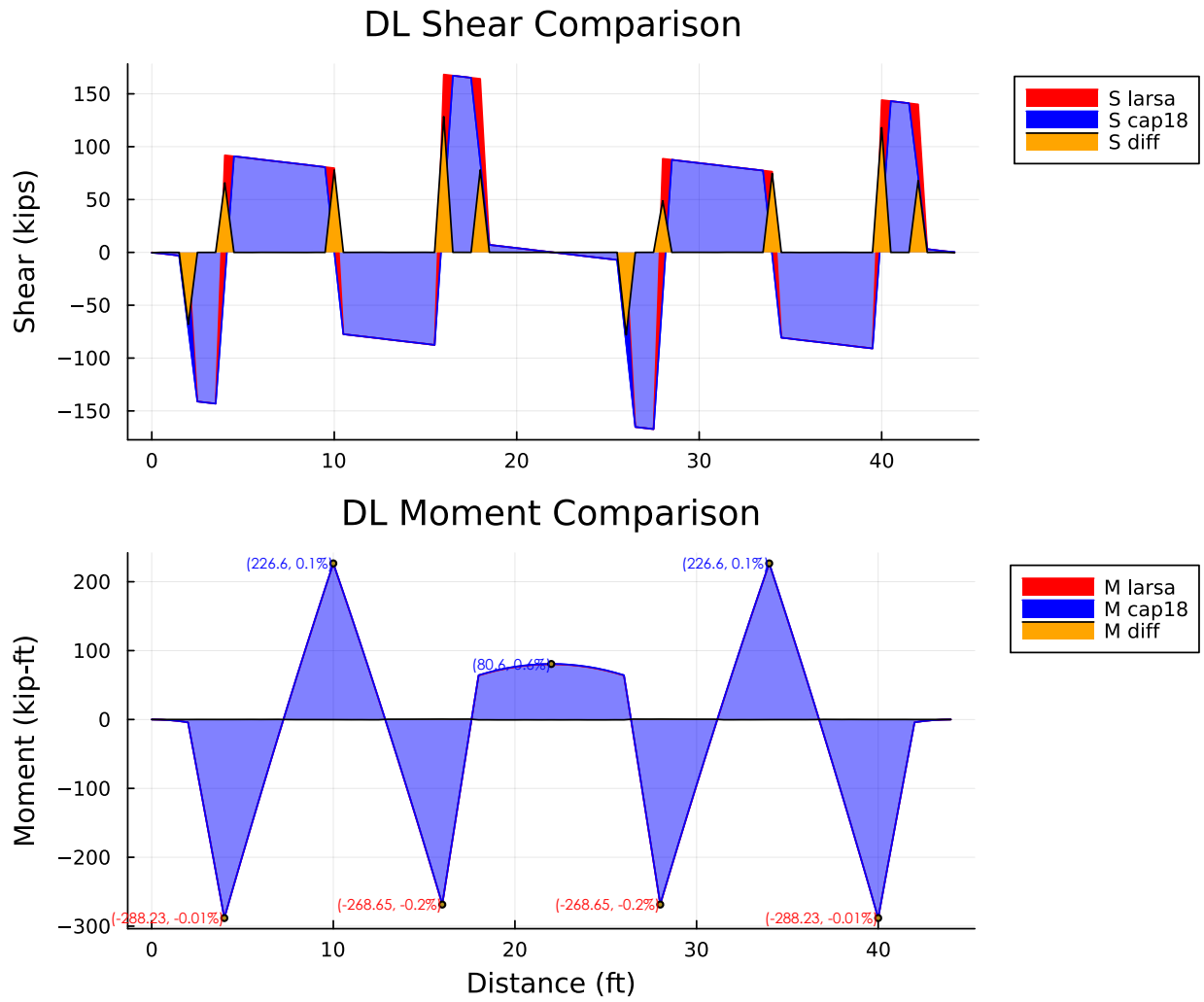

Figure 3.15: Comparison: DL Shear and Moment Diagrams

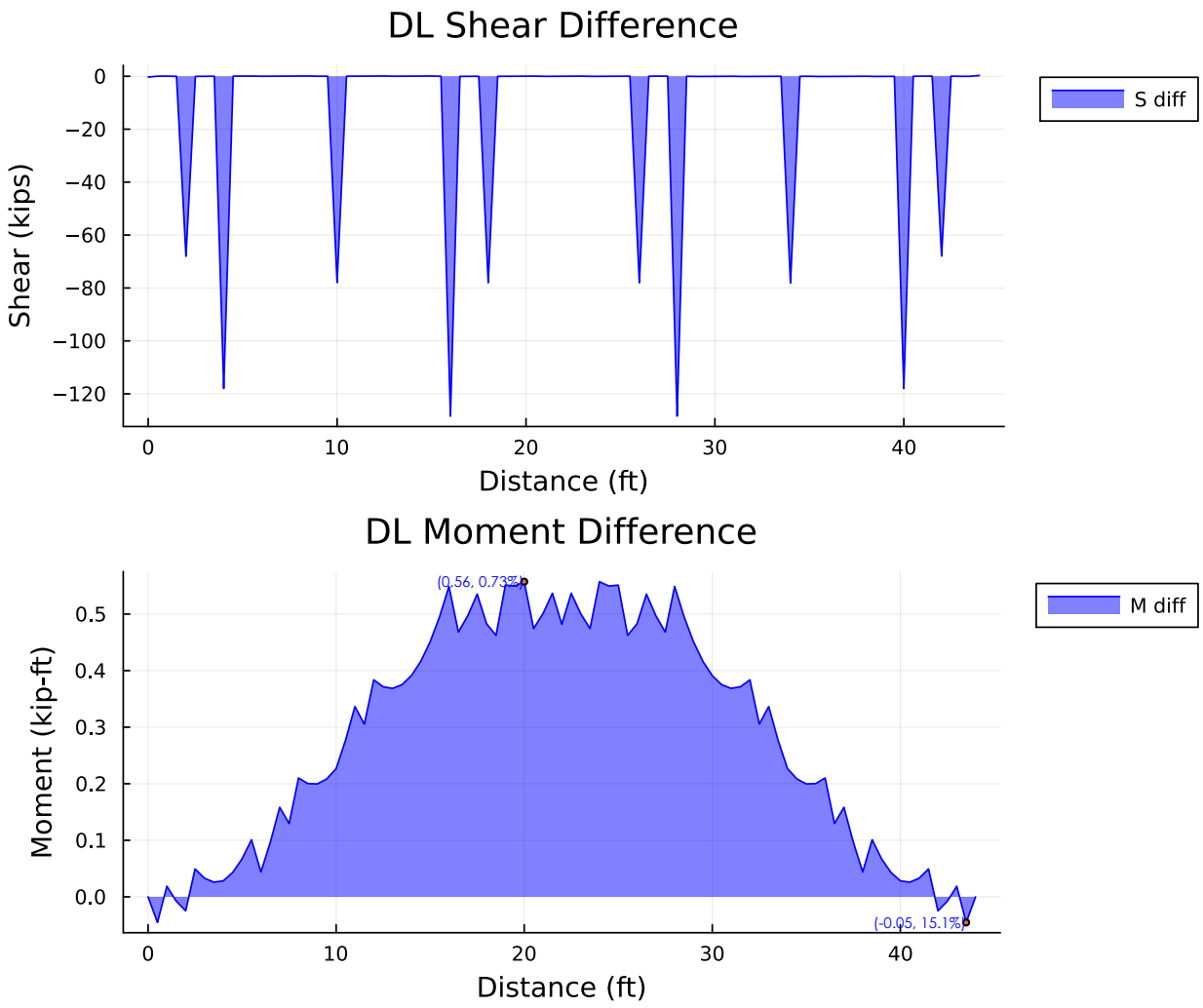

Figure 3.16: Comparison: DL Shear and Moment Difference

3.4.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

3.4.1.2.1 Maximum Envelope Comparison

The figures below compare the working stress results for the maximum stress envelope between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment and shears, the results are within 3%.

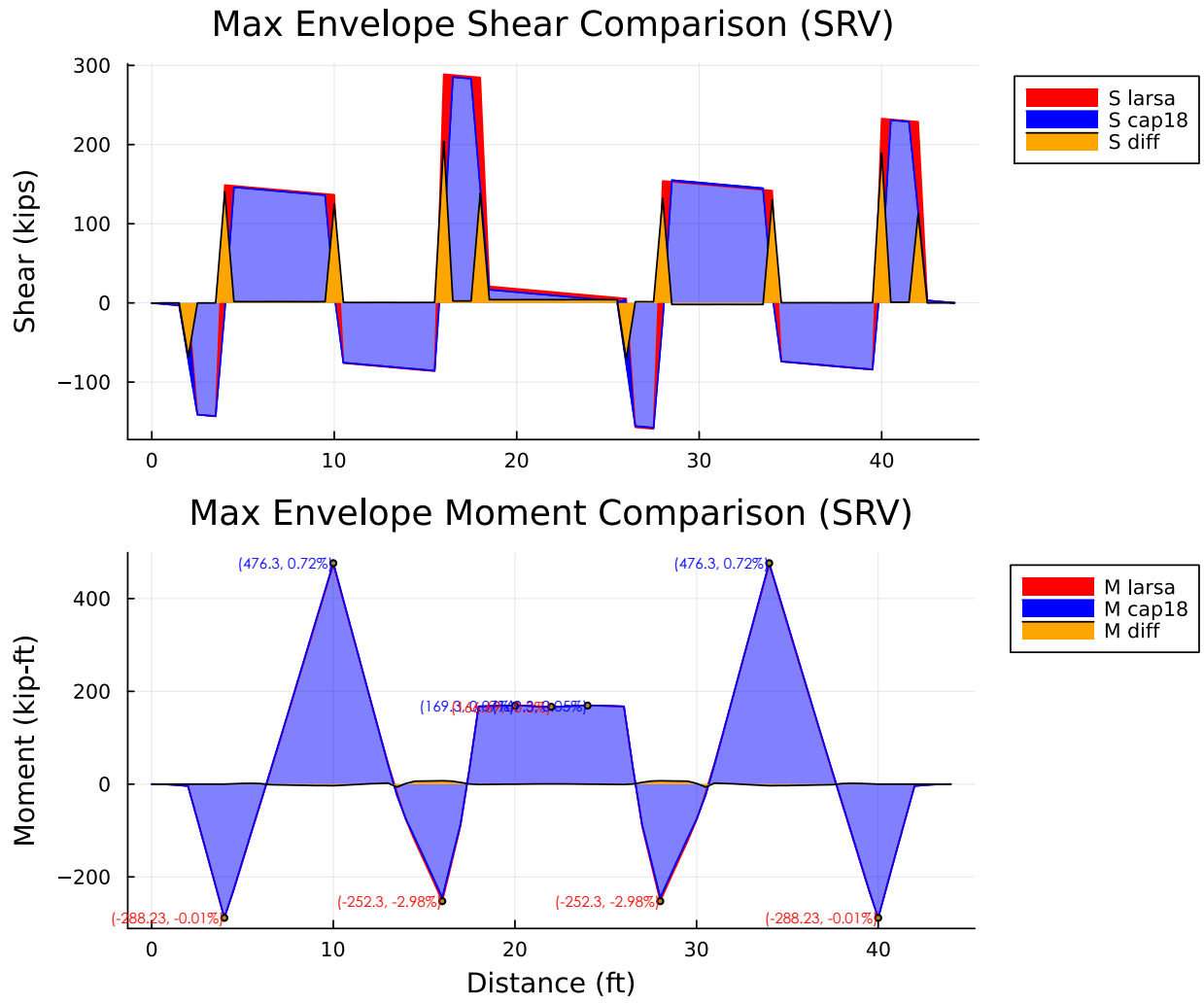

Figure 3.17: Comparison: Service Shear and Moment Max Envelope Diagrams

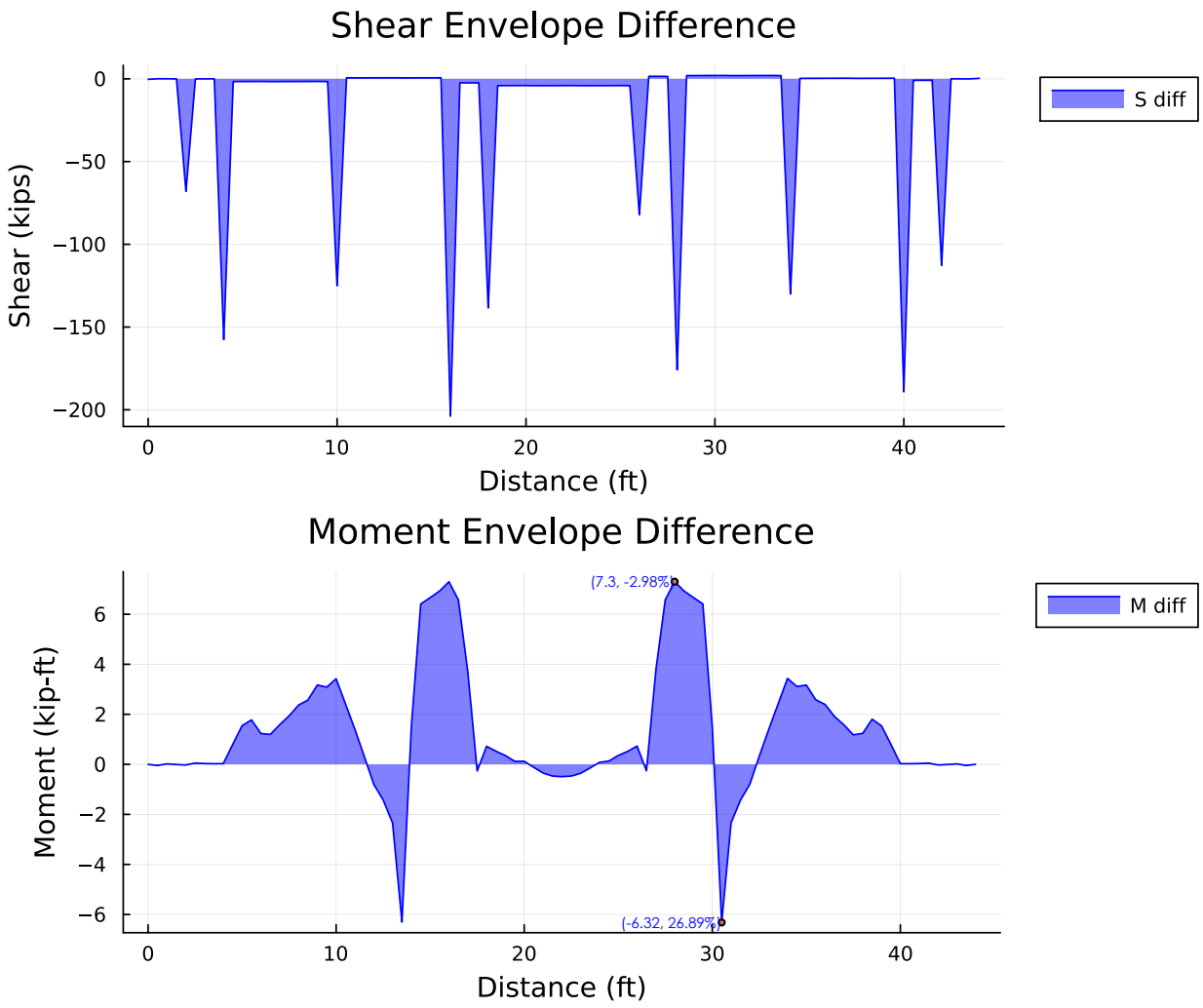

Figure 3.18: Comparison: Service Shear and Moment Max Envelope Difference

3.4.1.2.2 Minimum Envelope Comparison

The figures below compare the working stress results for the minimum stress envelope between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. . In areas of maximum moment and shears, the results are within 2%.

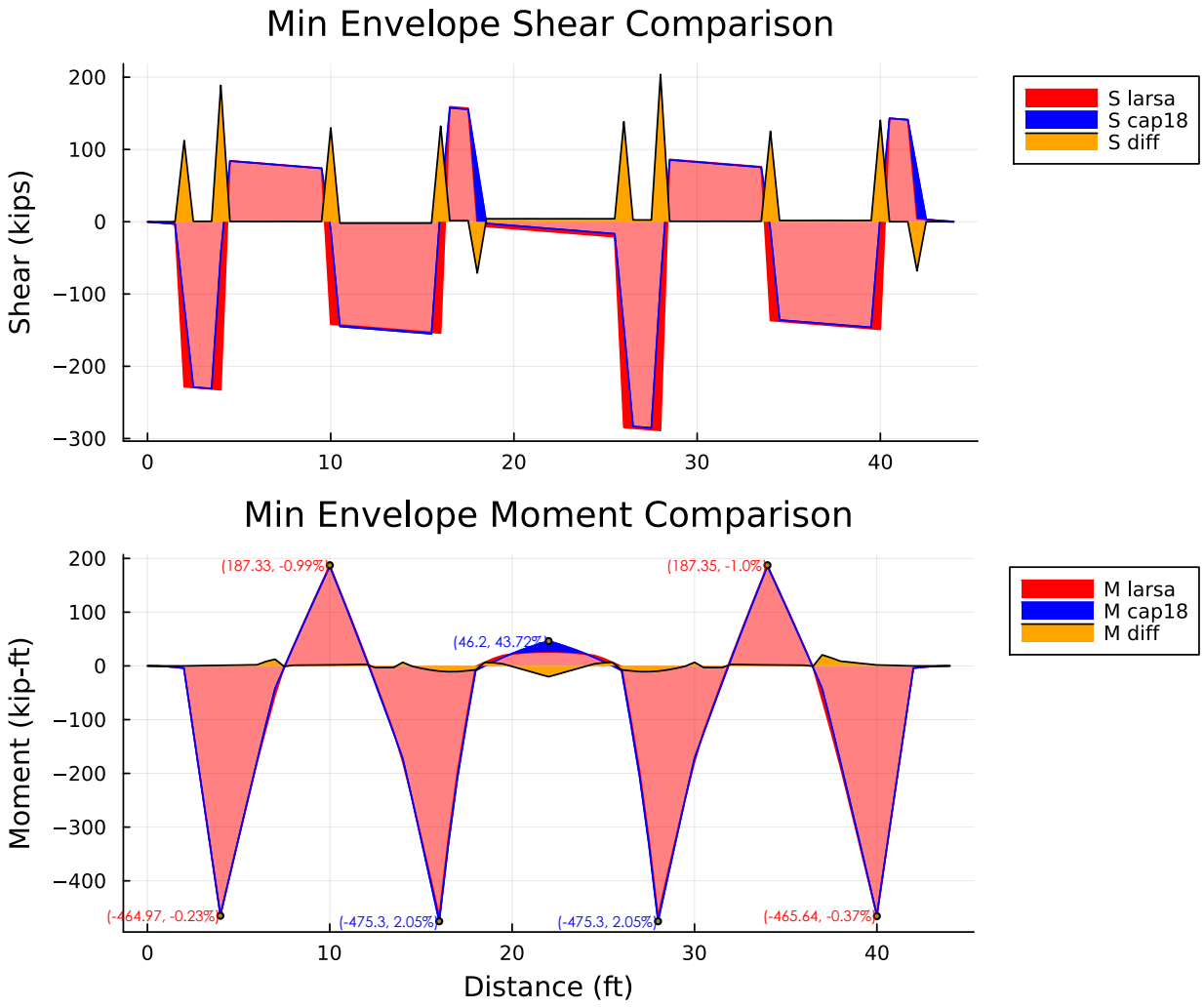

Figure 3.19: Comparison: Service Shear and Moment Min Envelope Diagrams

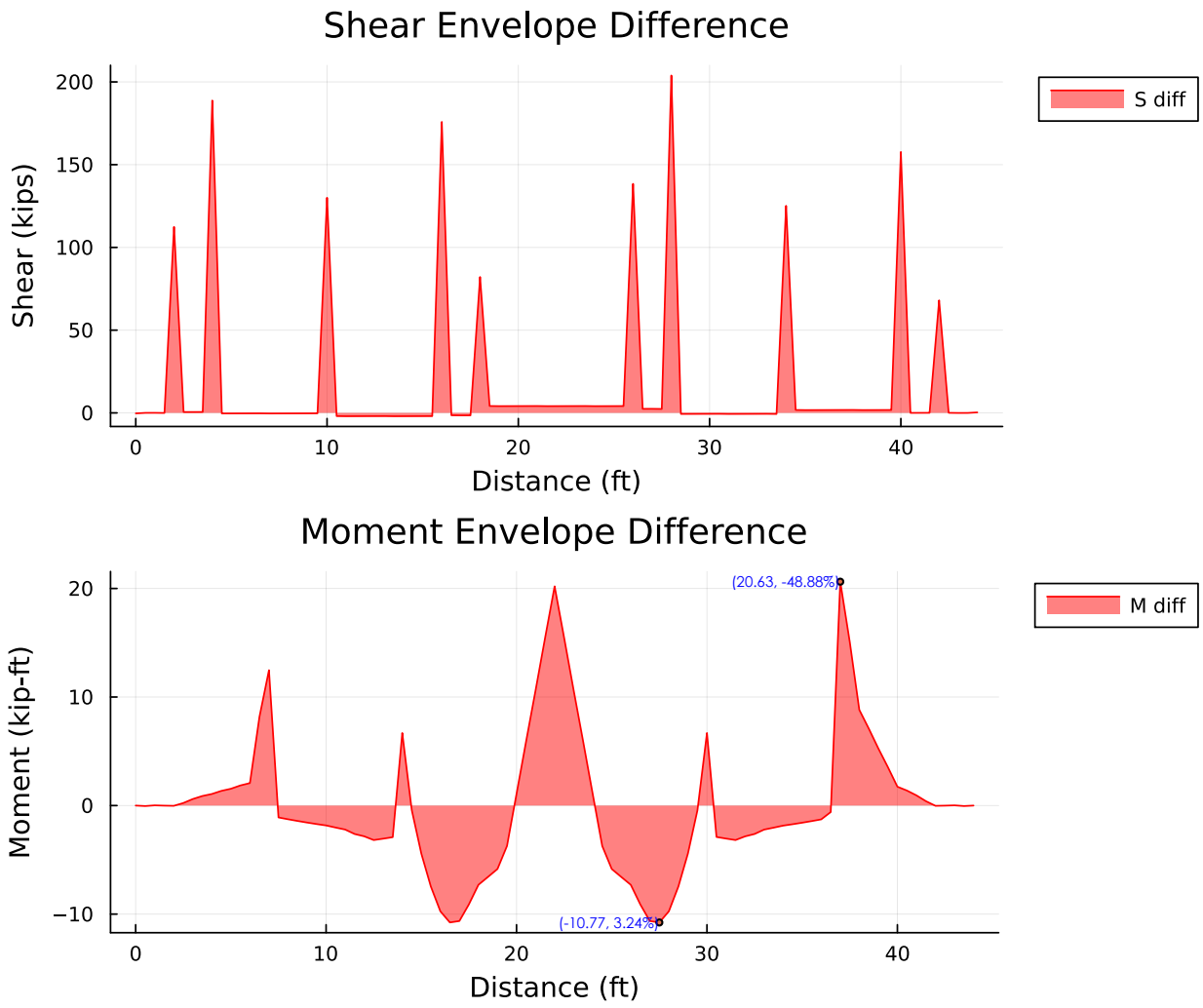

Figure 3.20: Comparison: Service Shear and Moment Min Envelope Difference

3.4.1.3 LIVE LOAD COMPARISON (SRV)

The figures below compare the working stress results for the maximum stress envelope of the live load between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, some of the differences can be explained by the difference in point load modeling between the two programs. The other shear areas where larsa results look to be higher in magnitude could potentially be explained by the difference in how the programs run the live load. The Larsa modeling of the live load is a little limited and conservative methods were used.

The maximum moment values are shown to be very similar. In areas of maximum moment, the results are within 2%.

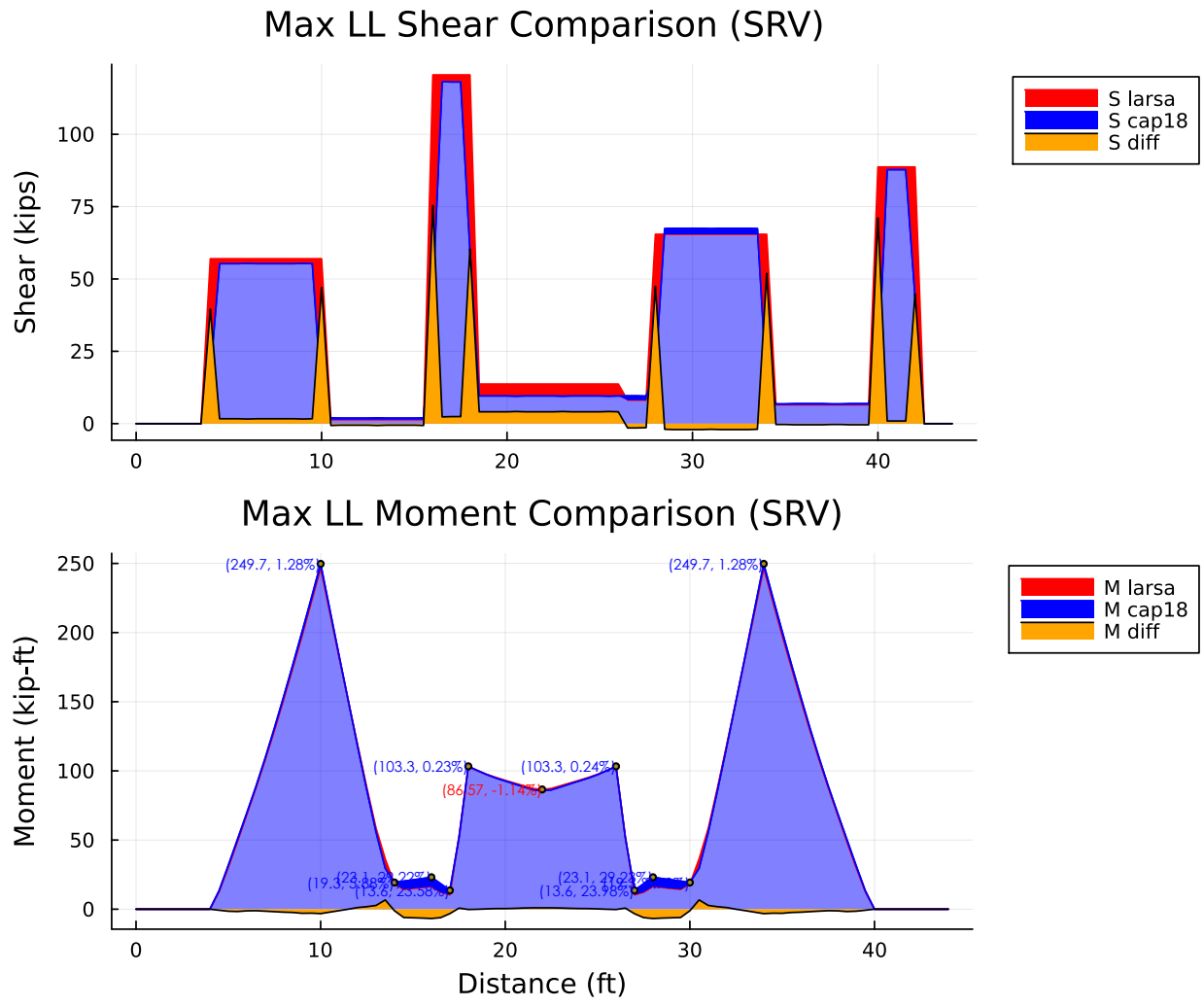

Figure 3.21: Comparison: Service Shear and Moment Max LL Envelope Diagrams

The figures below compare the working stress results for the minimum stress envelope of the live load between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. There are also large red spikes in the shear diagram for the larsa results. This is also a sign there are some unrealistic modeling behaviors in the larsa model.

The maximum moment values are shown to be very similar. In areas of maximum moment, the results are within 5%.

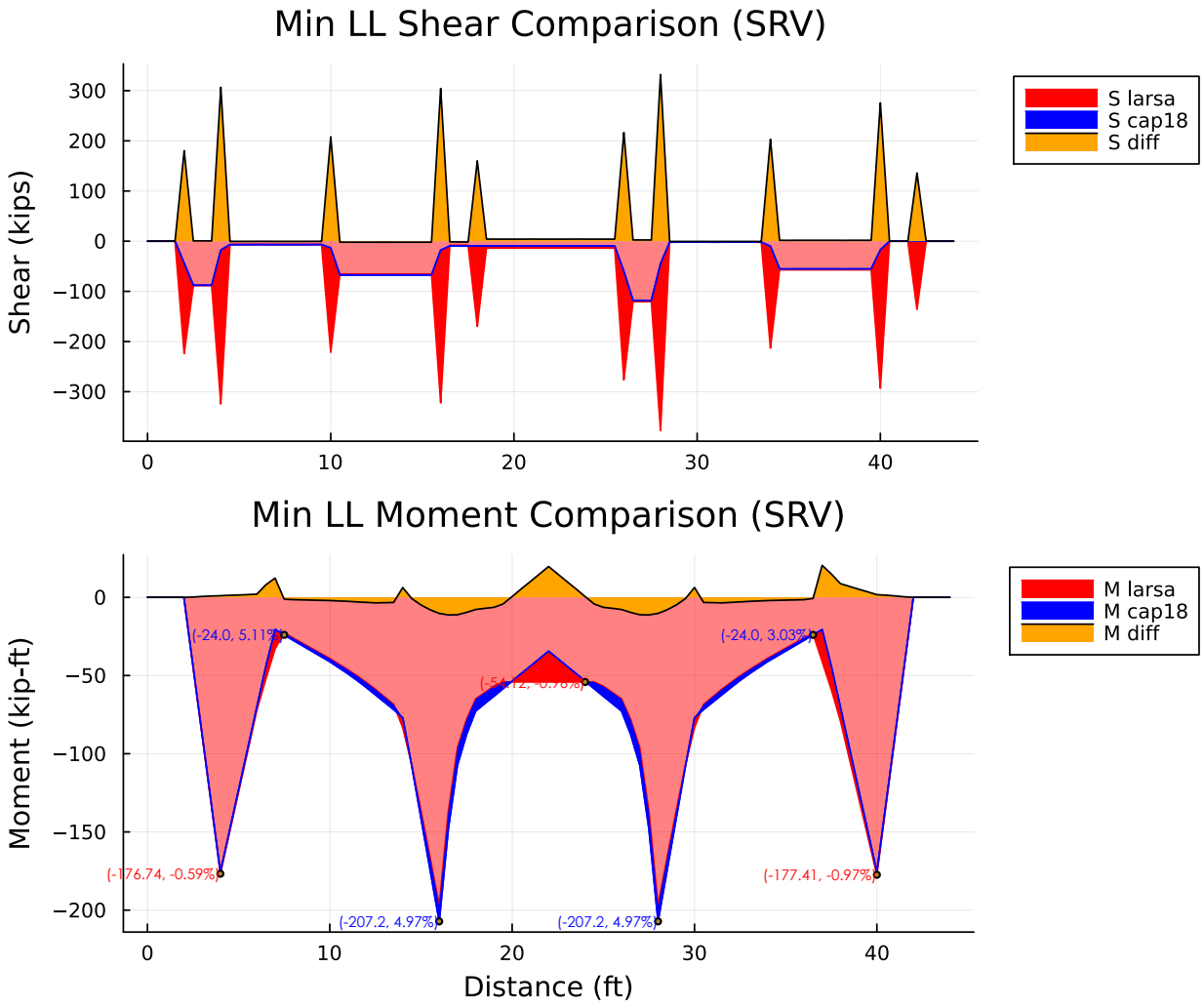

Figure 3.22: Comparison: Service Shear and Moment Min LL Envelope Diagrams

3.4.1.4 MAXIMUM SUPPORT REACTIONS (SRV)

The figure below compares the working stress results for the maximum and minimum reactions between the two programs. The results between programs are within 1% of eachother.

Figure 3.23: Comparison: Service Reactions

3.4.2 STR

3.4.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The figures below compare the load factor results for the maximum stress envelope between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment, the results are within 5%.

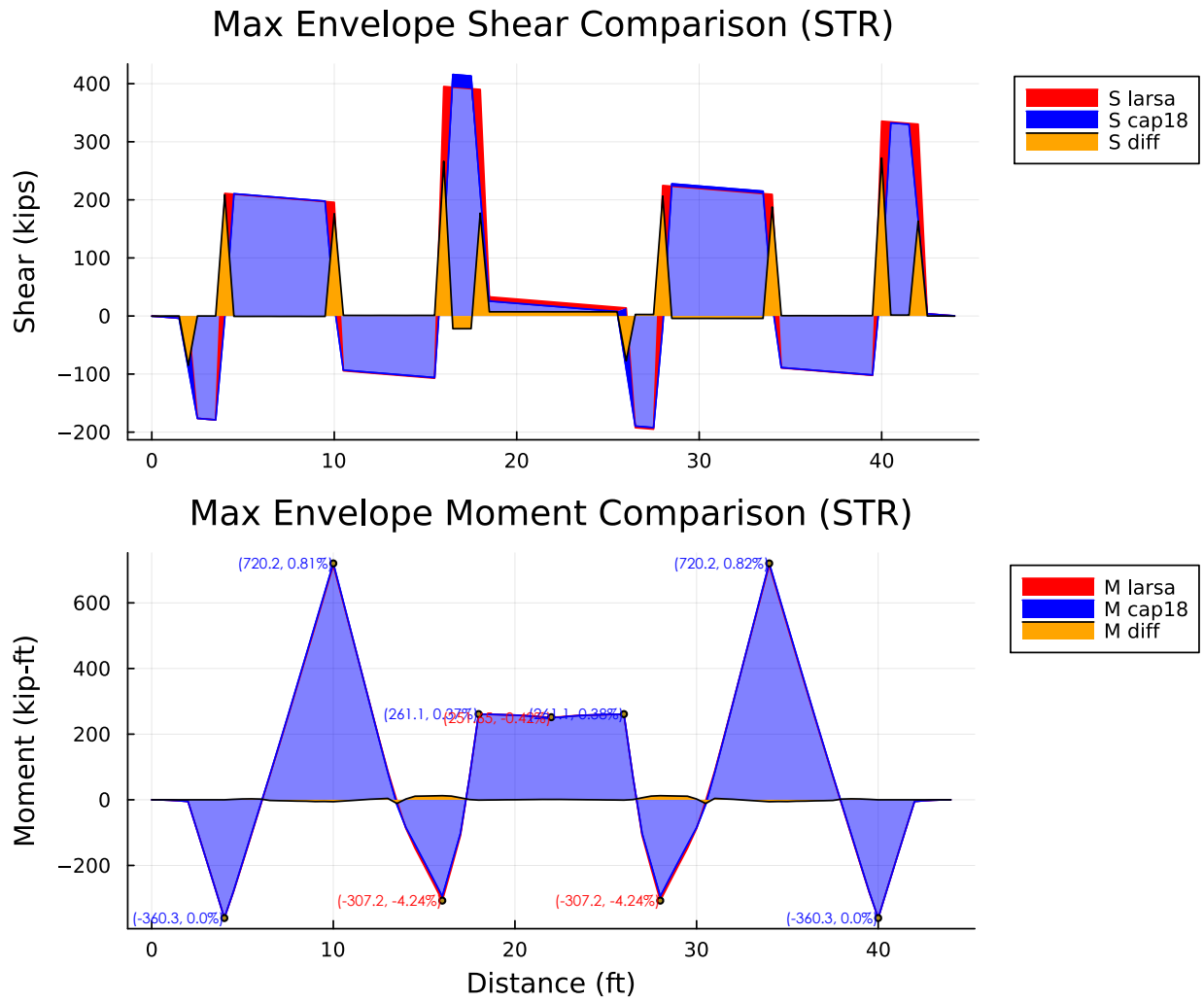

Figure 3.24: Comparison: Strength Shear and Moment Max Envelope Diagrams

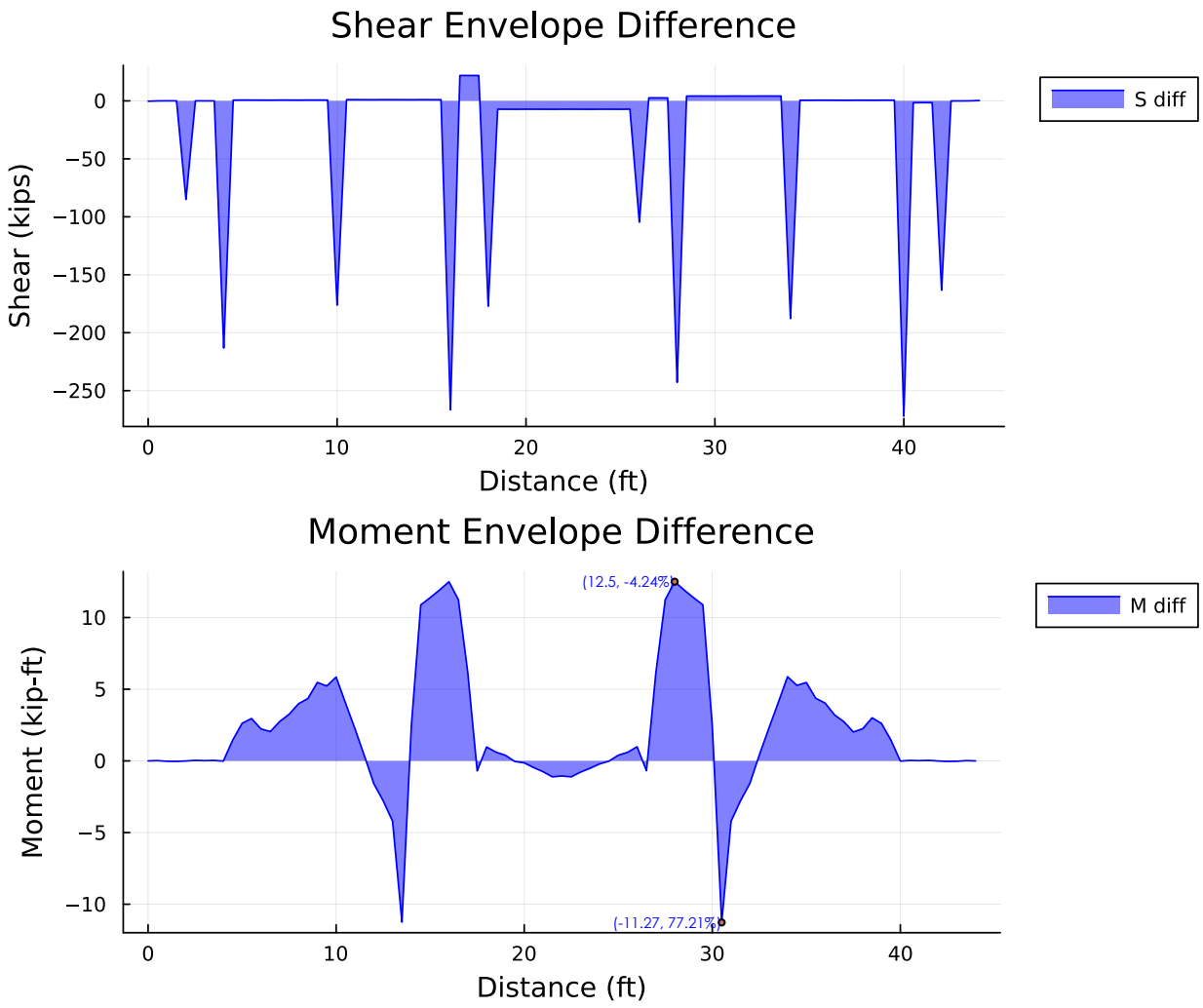

Figure 3.25: Comparison: Strength Shear and Moment Max Envelope Difference

The figures below compare the load factor results for the minimum stress envelope between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. . In areas of maximum moment and shears, the results are within 6%. Areas where larsa results are greater than cap18 are within 2%.

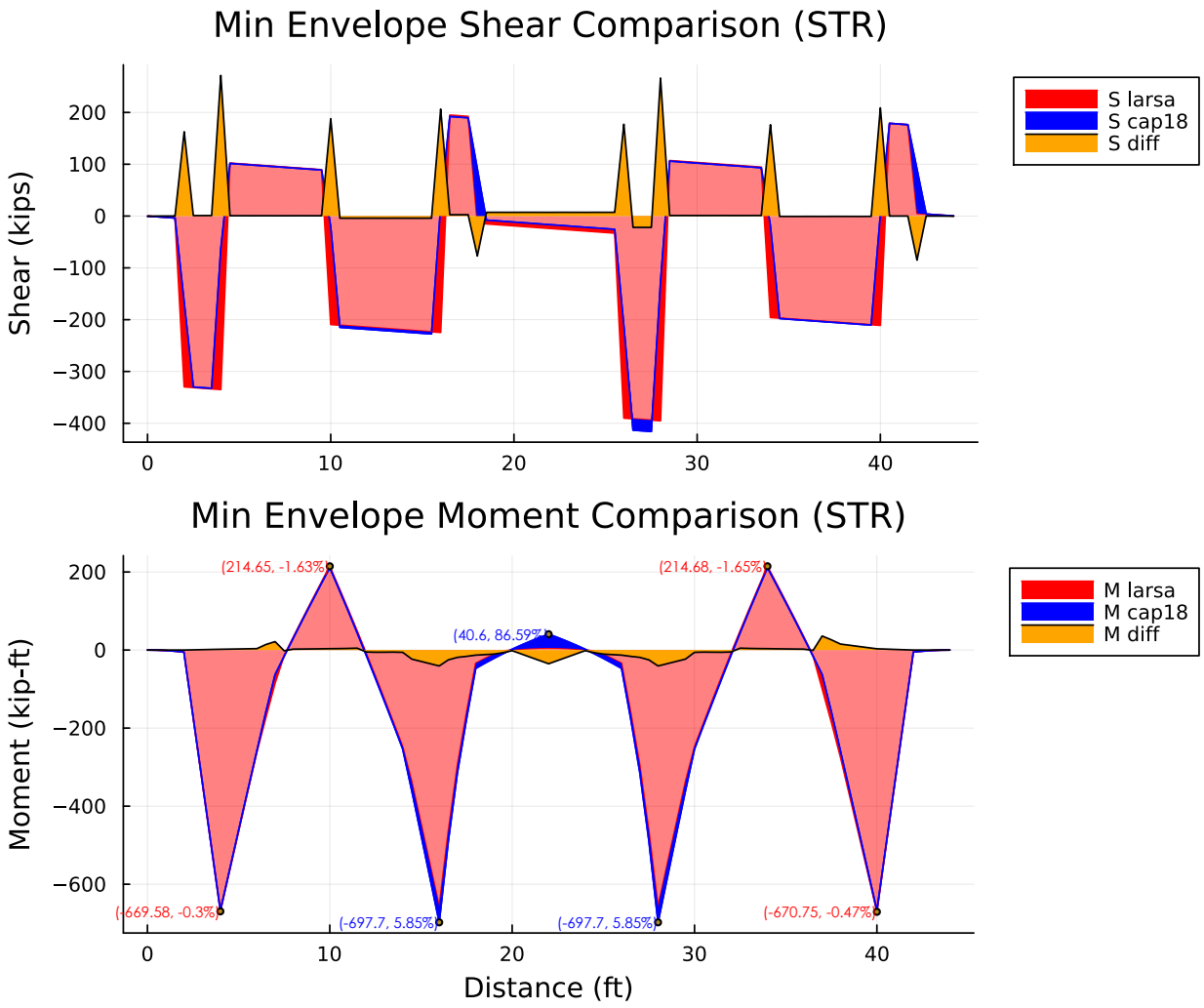

Figure 3.26: Comparison: Strength Shear and Moment Min LL Envelope Diagrams

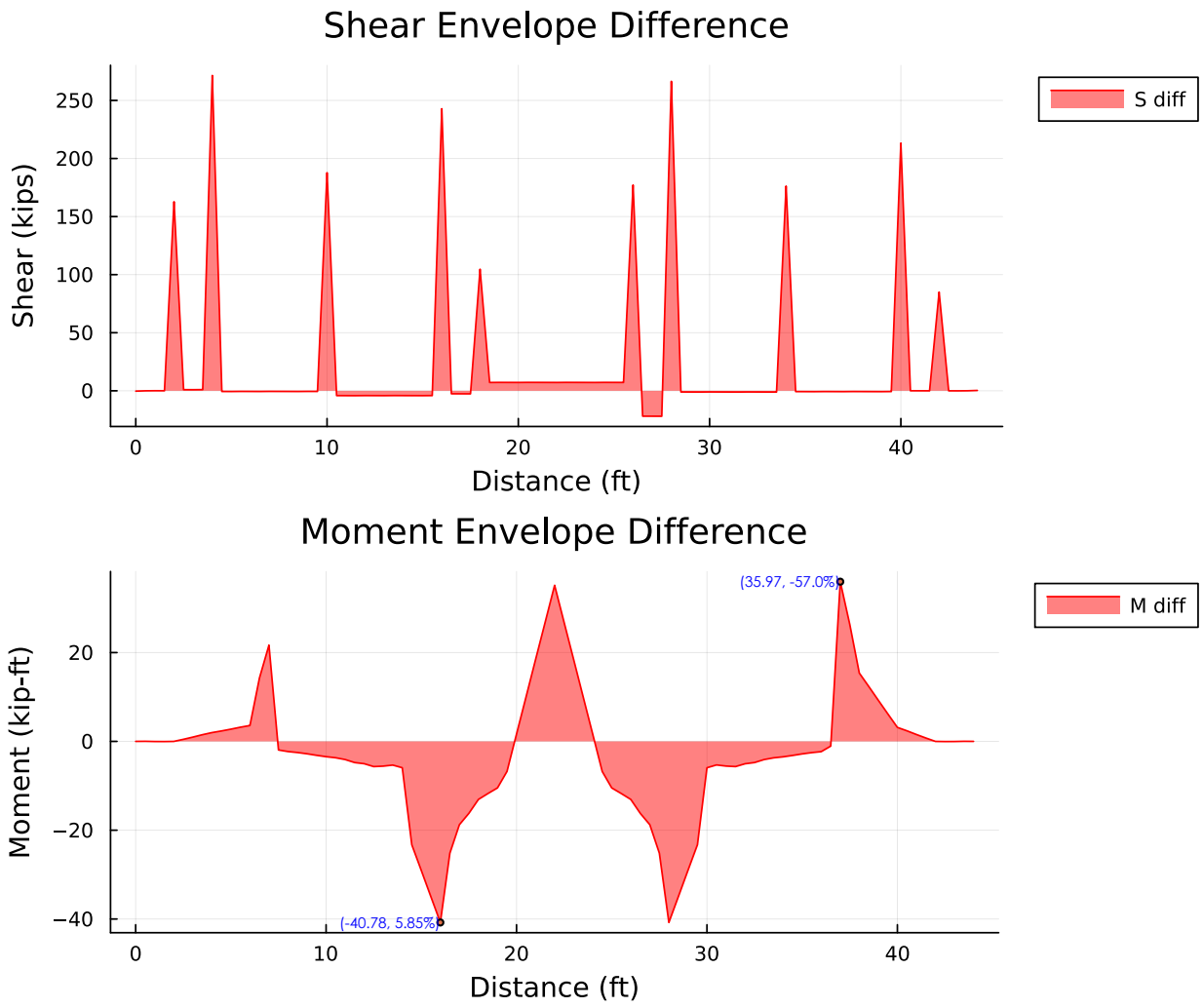

Figure 3.27: Comparison: Strength Shear and Moment Min Envelope Difference

3.4.2.2 LIVE LOAD COMPARISON (STR)

The figures below compare the load factor results for the maximum stress envelope of the live load between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment, the results are within 2% (when looking at the positive moments).

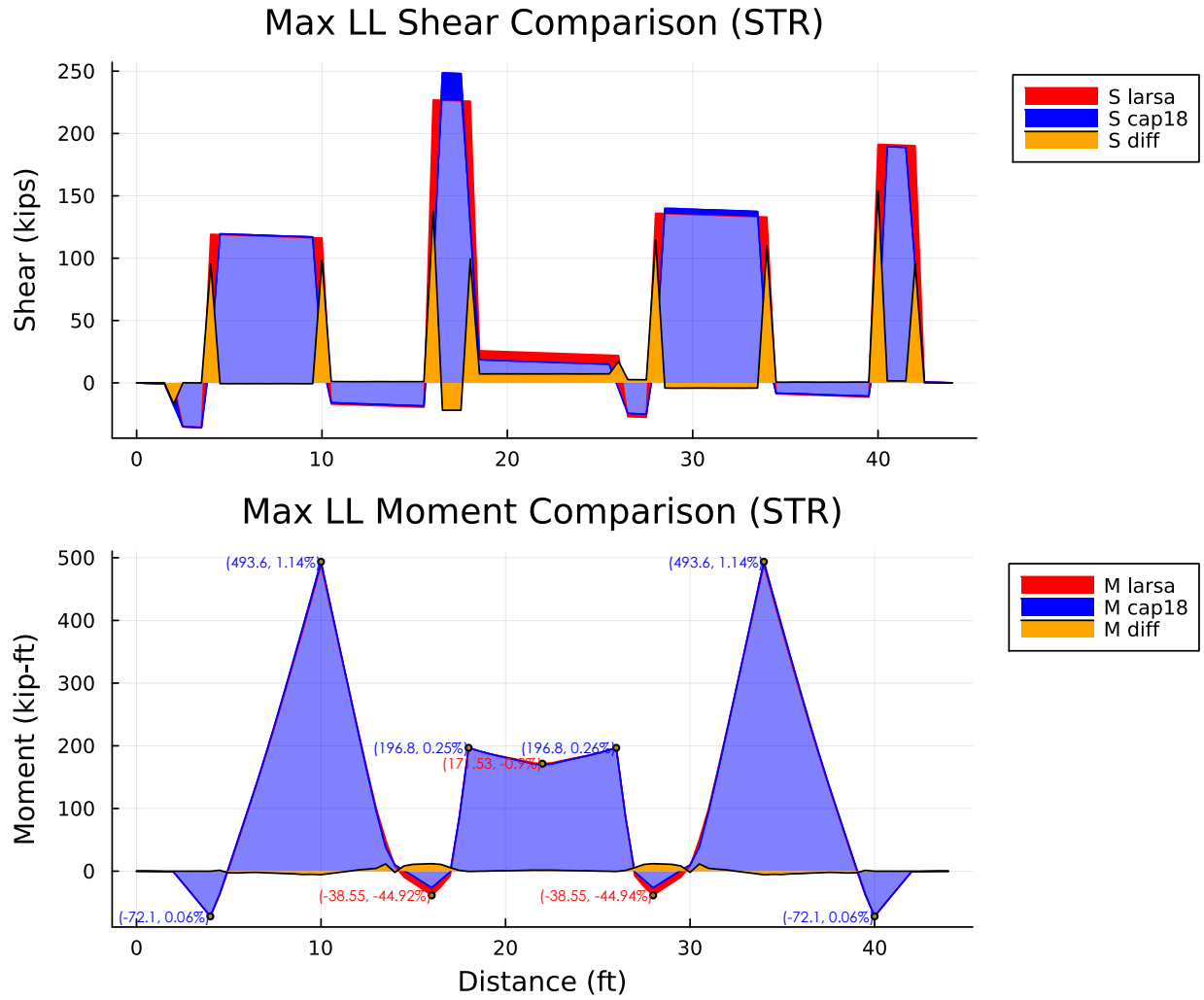

Figure 3.28: Comparison: Strength Shear and Moment Max LL Envelope Diagrams

The figures below compare the load factor results for the minimum stress envelope of the live load between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. There are also large red spikes in the shear diagram for the larsa results. This is also a sign there are some unrealistic modeling behaviors in the larsa model.

In areas of maximum moment, the results are greater at 10%. However, with the limitations of the larsa model, this is not alarming. Cap18 results are higher and the program is doing a better job at maximizing the controlling areas. The maximum negative moment areas where larsa is higher is within 1%.

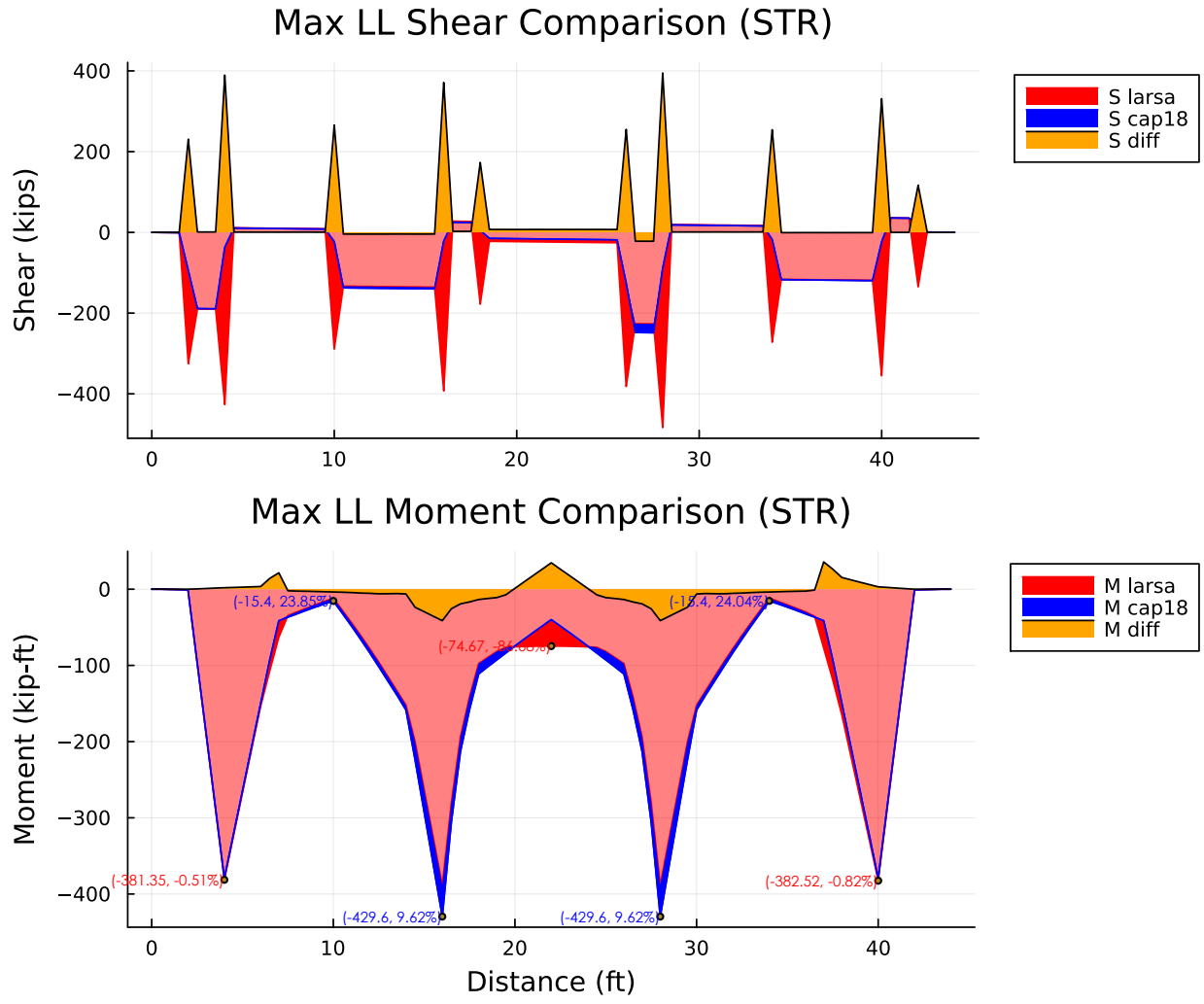

Figure 3.29: Comparison: Strength Shear and Moment Min LL Envelope Diagrams

3.4.2.3 MAXIMUM SUPPORT REACTIONS (STR)

The figure below compares the load factor results for the maximum and minimum reactions between the two programs. The results between programs are within 7% of eachother. The Cap18 results are higher for those higher percentage differences.

Figure 3.30: Comparison: Strength Reactions

4. Example 2 - Six Column Bent (Back Span)

4.1 Bent Summary

Example 2 was run for both Larsa and Cap18. Example 2 needed two separate runs to effectively analyze for the backspan and the forward span. This is the analysis of the back span part of the example. Below is a short summary of the bent details.

Bent Details:

- 9 Tx54 backspan girders
- 10 Tx54 forwardspan girders
- 78’ wide bent
- 6 columns spaced at 14’

4.1.1 Back Span

The figure below shows the beam spacing for the backspan girders. Since Cap18 works in half-foot increments, the beam spacing was rounded to the nearest increments. Both Cap18 and Larsa have the same spacing for the beams.

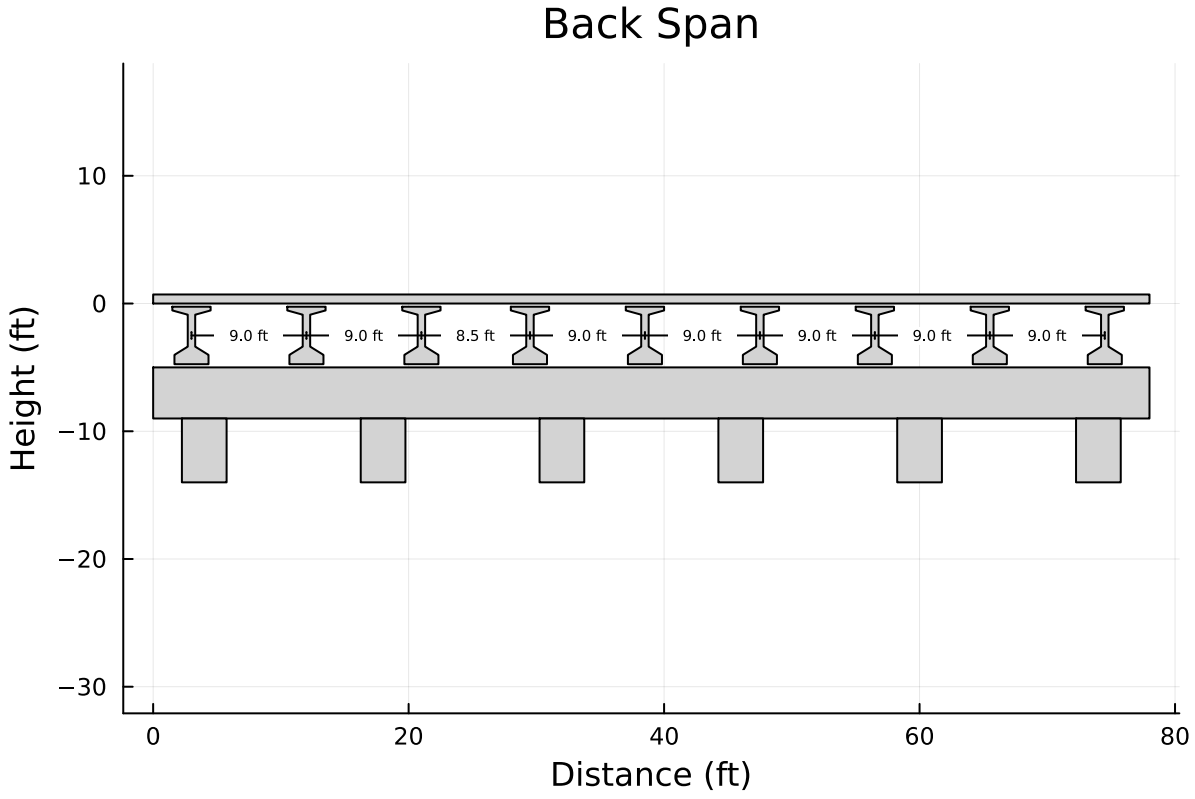

Figure 4.1: Section View of Back Span

4.1.2 Forward Span

The figure below shows the beam spacing for the forwardspan girders.

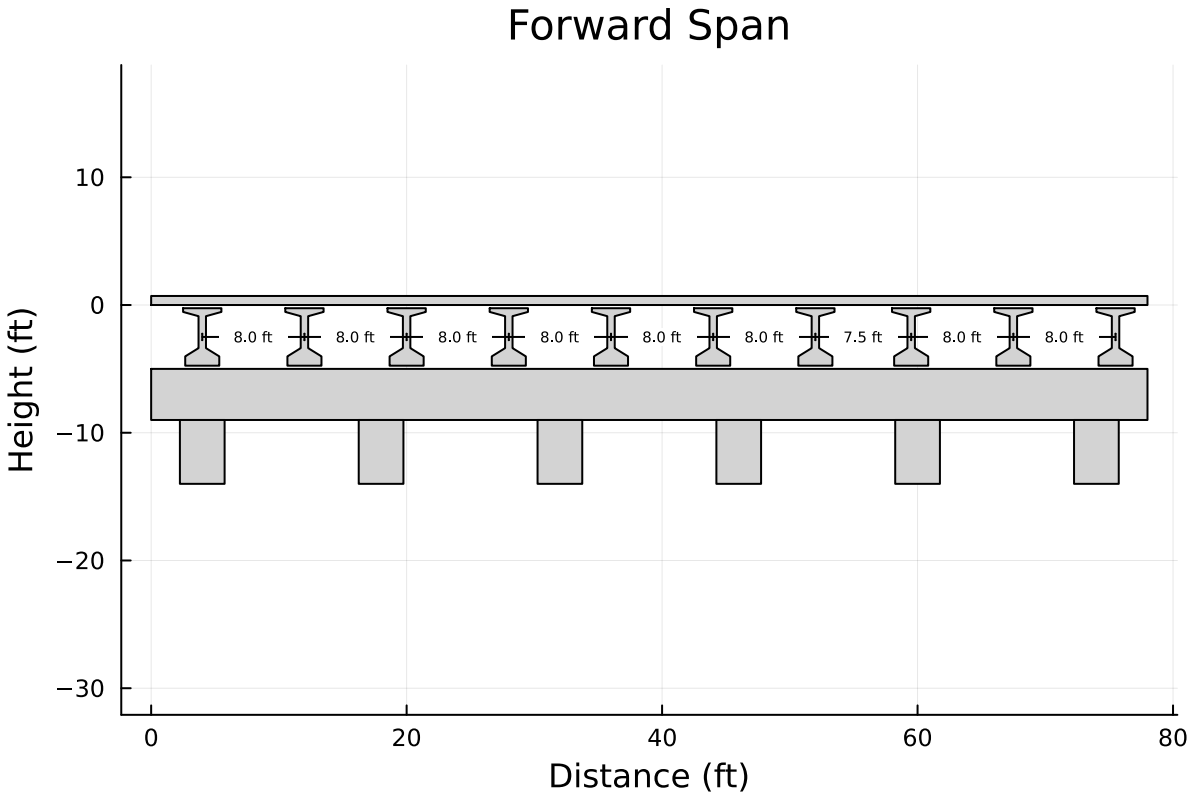

Figure 4.2: Section View of Forward Span

4.2 Cap 18

A Cap18 input file was created and ran for the above bent. The output file was then parsed for the dead load, working stress, and load factor cases. The summary of the findings are discussed below.

4.2.1 SRV

4.2.1.1 DEAD LOAD RESULTS (SRV)

The dead load results were plotted on top of the bent to get a better visual understanding of the results. Based on the DL shear and moment diagrams below, the Cap18 results look to align well with the bent. Sharp changes in shear happen in areas with either a column or a beam, and negative moments are maximized over the columns. This indicates to some degree that the expected behavior of the stresses within the cap is being captured by the Cap18 program. A more detailed comparison with Larsa results will help determine if the magnitudes of these stresses are correct.

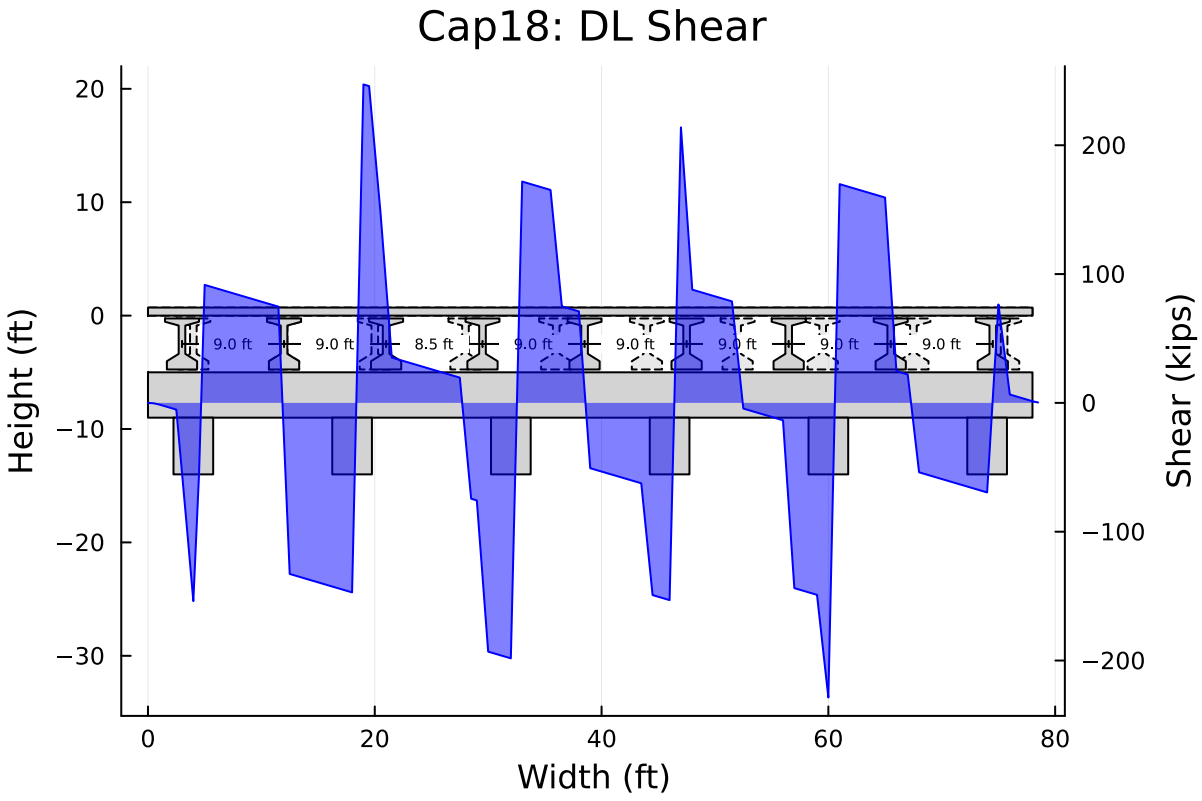

Figure 4.3: Cap18: DL Shear Diagram

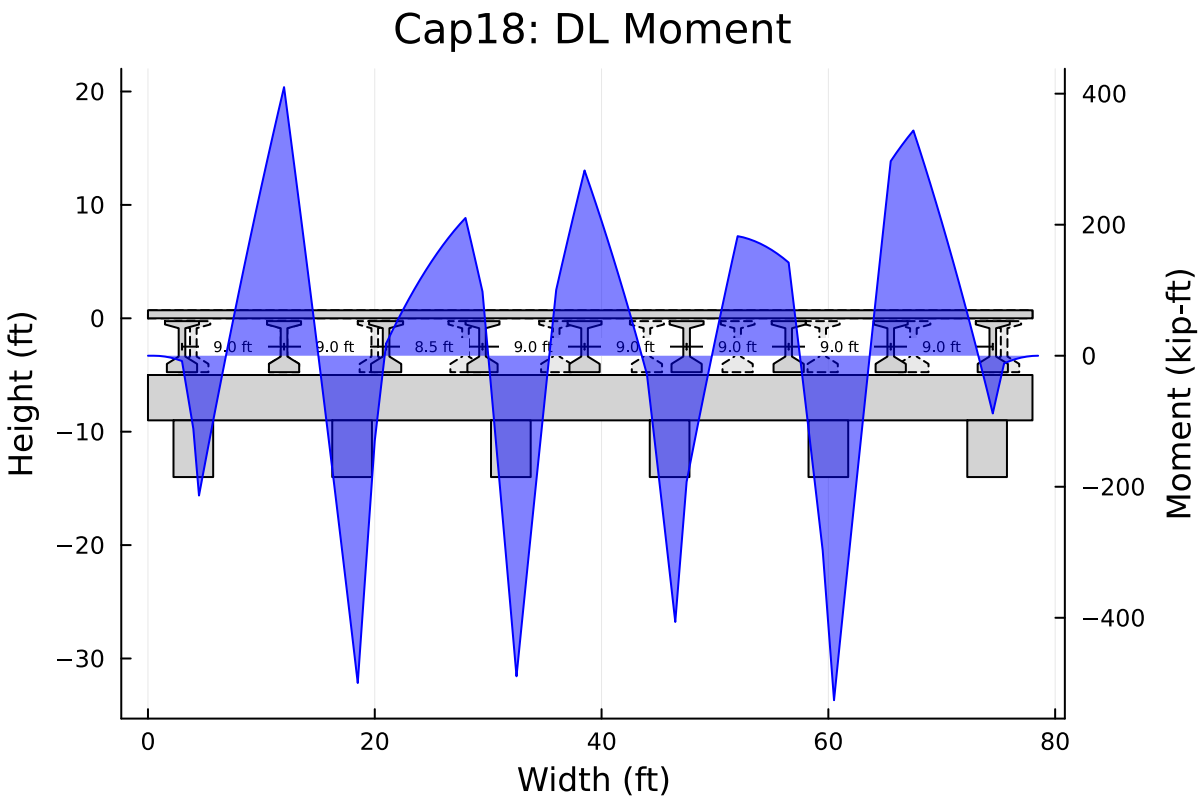

Figure 4.4: Cap18: DL Moment Diagram

4.2.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

The working stress results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Larsa is needed.

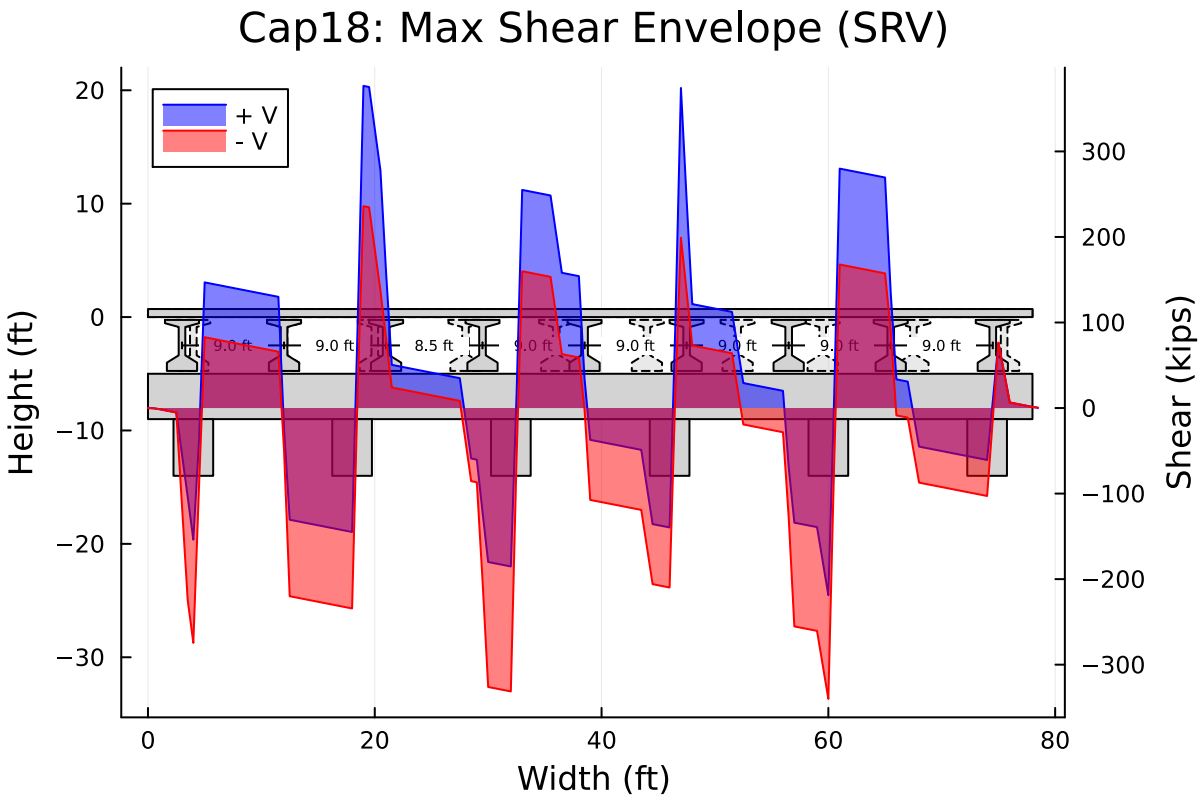

Figure 4.5: Cap18: Service Shear Envelope Diagram

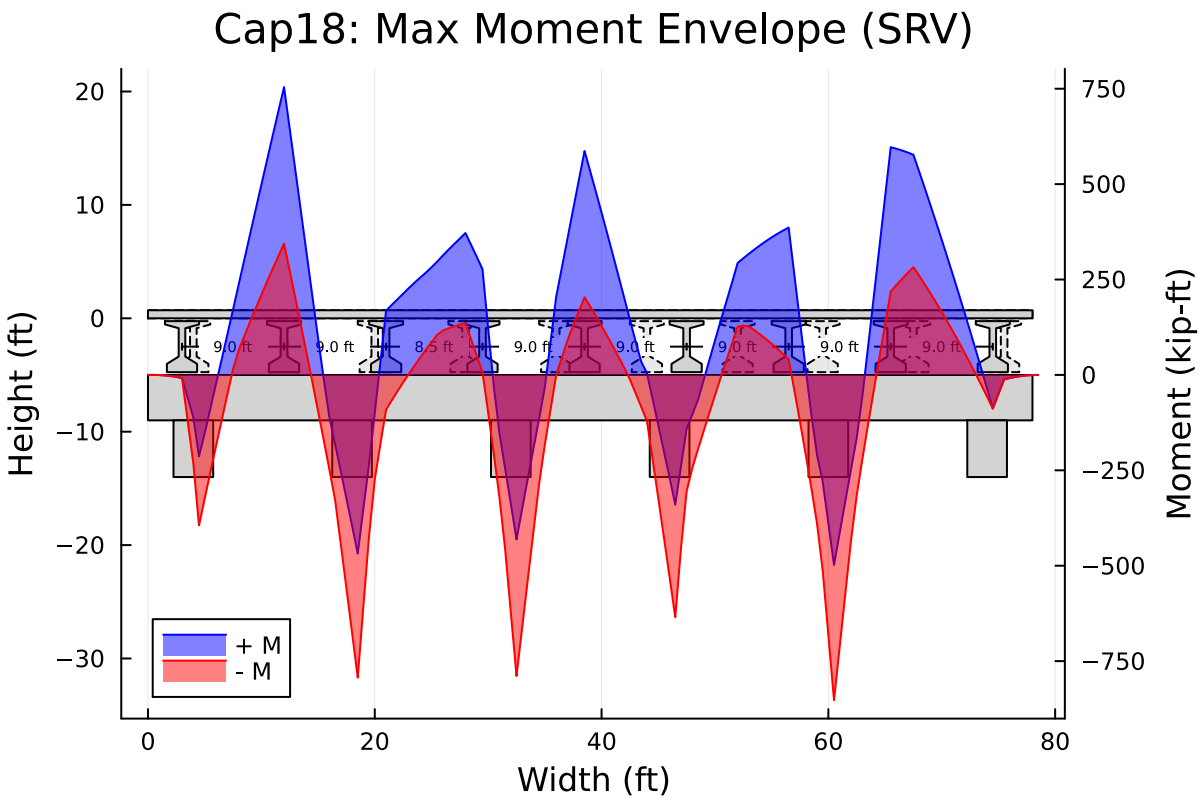

Figure 4.6: Cap18: Service Moment Envelope Diagram

4.2.1.3 MAXIMUM SUPPORT REACTIONS (SRV)

The maximum and minimum support reactions for the working stress case are listed in the table below.

Table 6. Cap18: Service Reactions

Station	Distance	Max Reactions	Min Reactions
9	4.5 ft	465.3 kip	288.4 kip
37	18.5 ft	613.5 kip	383.5 kip
65	32.5 ft	587.7 kip	347.7 kip
93	46.5 ft	585.6 kip	341.3 kip
121	60.5 ft	622.6 kip	389.2 kip
149	74.5 ft	427.3 kip	267.5 kip

4.2.2 STR

4.2.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The load factor results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Larsa is needed.

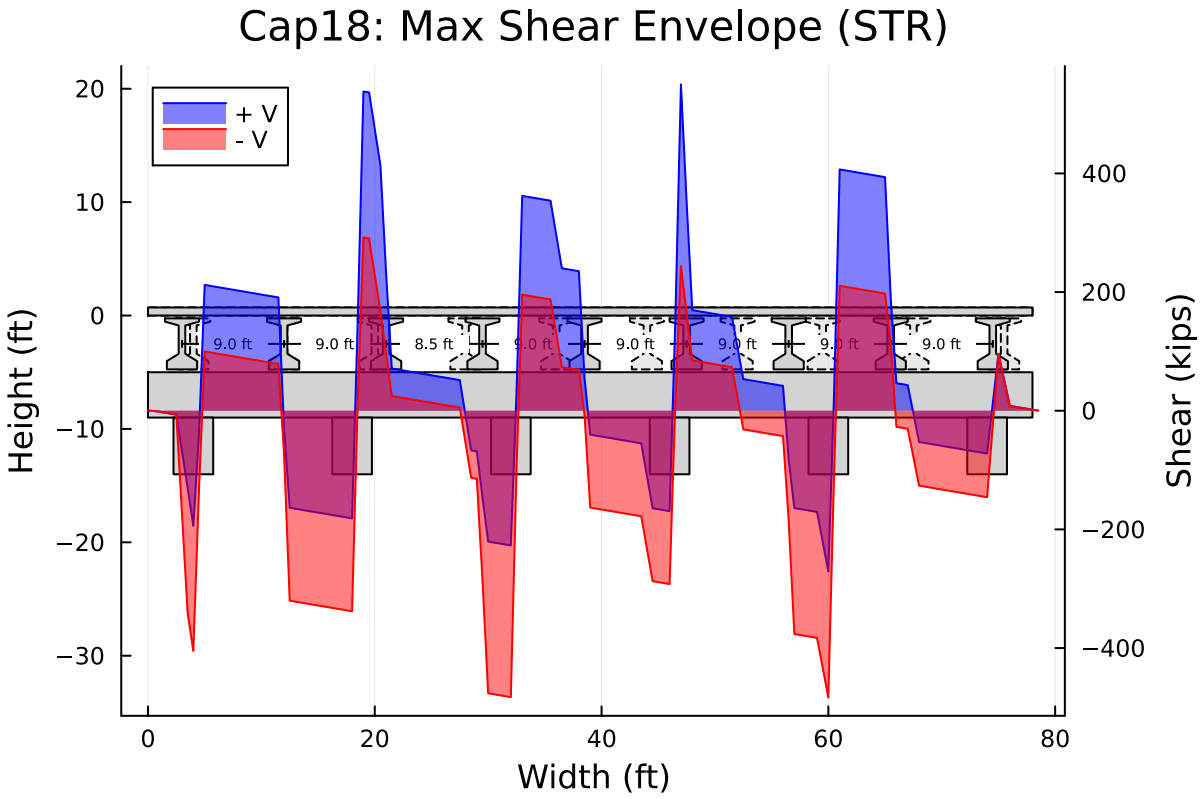

Figure 4.7: Cap18: Strength Shear Envelope Diagram

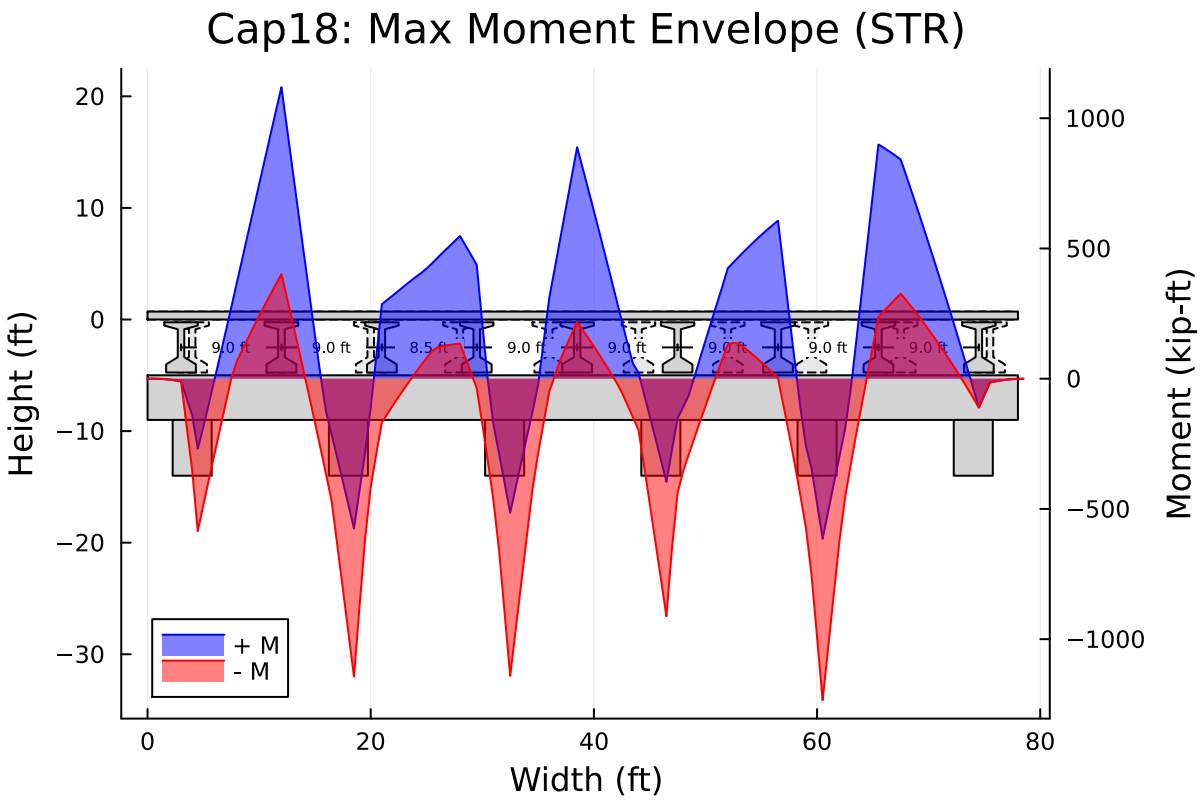

Figure 4.8: Cap18: Strength Moment Envelope Diagram

4.2.2.2 MAXIMUM SUPPORT REACTIONS (STR)

The maximum and minimum support reactions for the load factor case are listed in the table below.

Table 7. Cap18: Strength Reactions

Station	Distance	Max Reactions	Min Reactions
9	4.5 ft	668.3 kip	358.8 kip
37	18.5 ft	879.4 kip	476.8 kip
65	32.5 ft	846.0 kip	426.0 kip
93	46.5 ft	843.7 kip	416.3 kip
121	60.5 ft	893.2 kip	484.7 kip
149	74.5 ft	612.1 kip	332.4 kip

4.3 Larsa Results

A Larsa model was created and ran for the above bent. The loads were extracted for the dead load, working stress, and load factor cases. The summary of the findings are discussed below.

4.3.1 SRV

4.3.1.1 DEAD LOAD RESULTS (SRV)

The dead load results were plotted on top of the bent to get a better visual understanding of the results. Based on the DL shear and moment diagrams below, the Larsa results look to align well with the bent. A more detailed comparison with the Cap18 results will help determine if the magnitudes of the stresses calculated from the Cap18 program are correct.

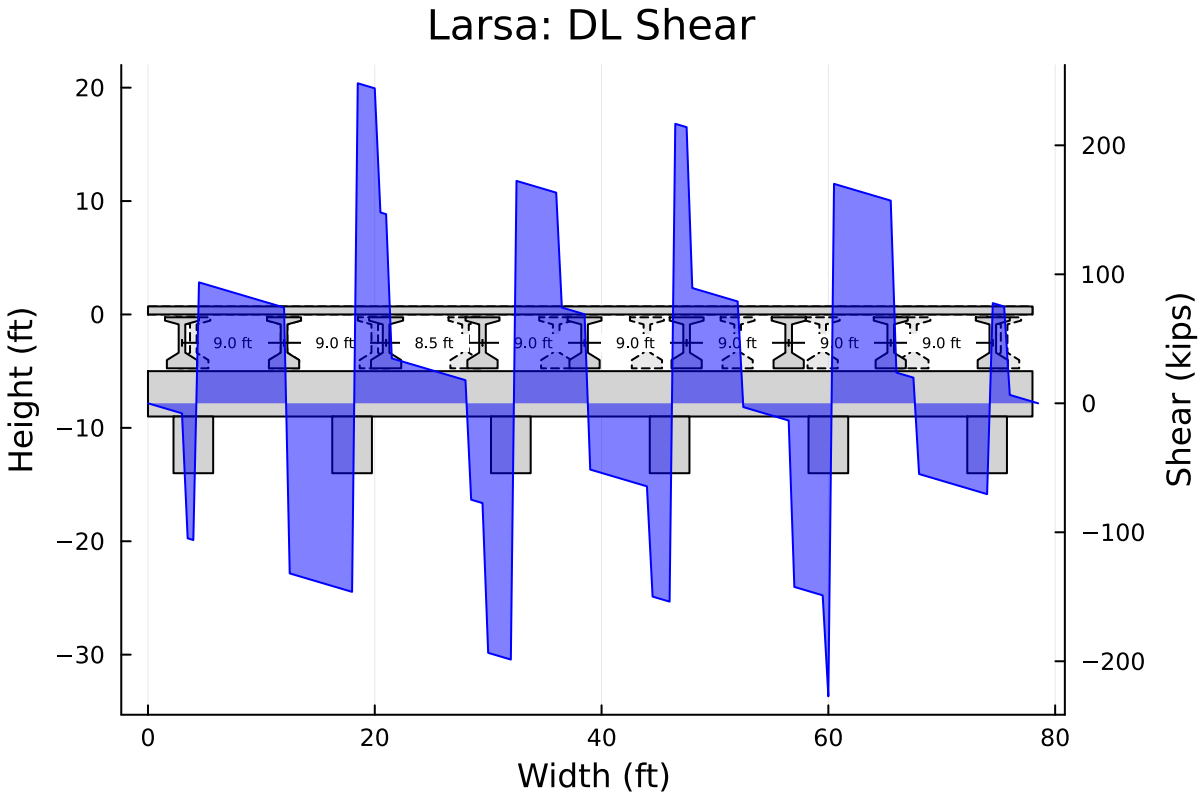

Figure 4.9: LARSA: DL Shear Diagram

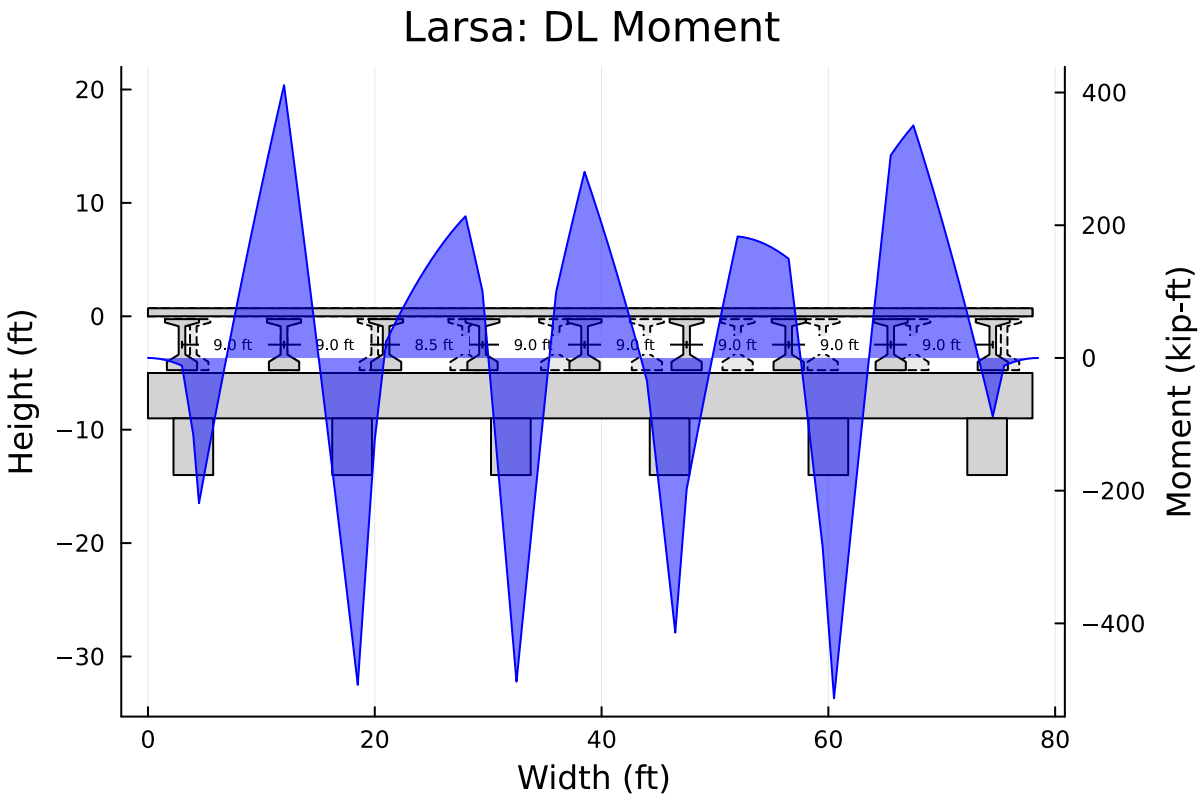

Figure 4.10: LARSA: DL Moment Diagram

4.3.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

The working stress results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Cap18 is needed.

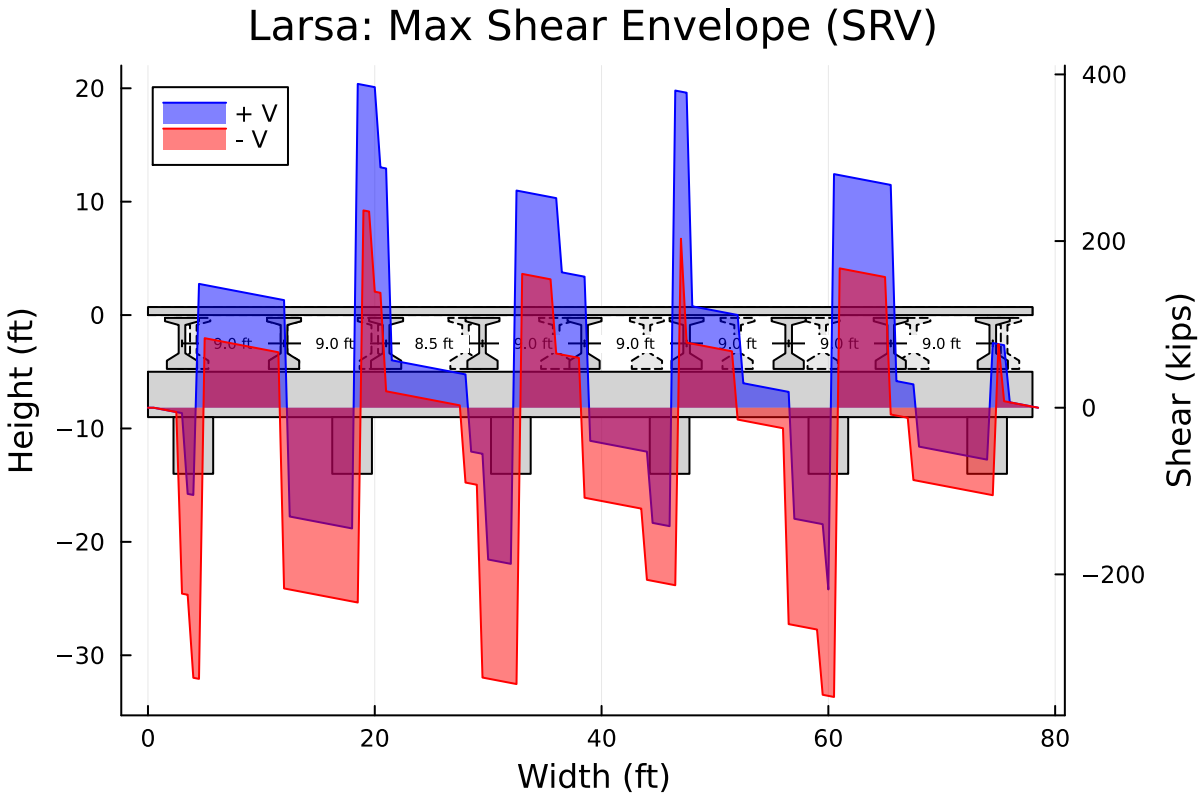

Figure 4.11: LARSA: Service Shear Envelope Diagram

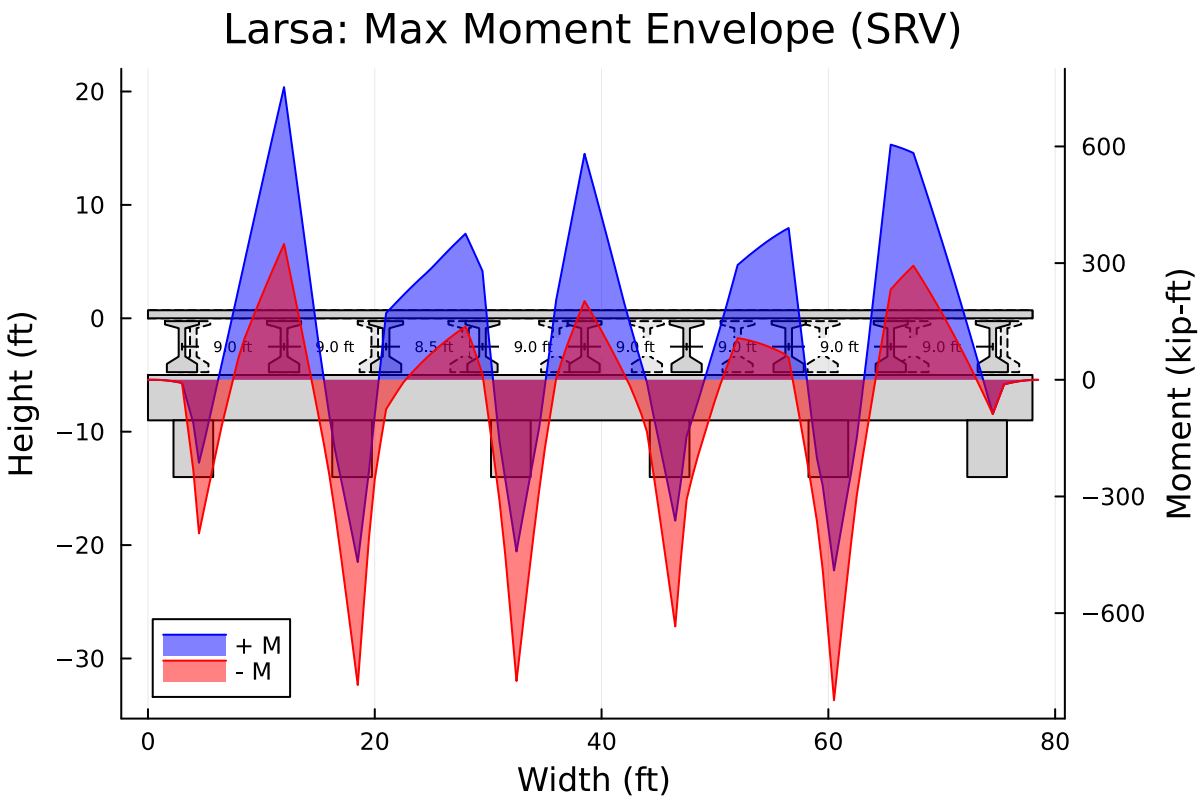

Figure 4.12: LARSA: Service Moment Envelope Diagram

4.3.1.3 MAXIMUM SUPPORT REACTIONS (SRV)

The maximum and minimum support reactions for the working stress case are listed in the table below.

Table 8. LARSA: Service Reactions

Station	Distance	Max Reactions	Min Reactions
9	4.5 ft	465.86 kip	289.142 kip
37	18.5 ft	616.513 kip	384.262 kip
65	32.5 ft	585.038 kip	350.561 kip
93	46.5 ft	586.099 kip	347.547 kip
121	60.5 ft	617.082 kip	387.892 kip
149	74.5 ft	437.109 kip	269.025 kip

4.3.2 STR

4.3.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The load factor results were plotted on top of the bent to get a better visual understanding of the results. The results can be seen in the figures below. These stresses follow the same expected behavoir as the DL stresses. Further comparison with Cap18 is needed.

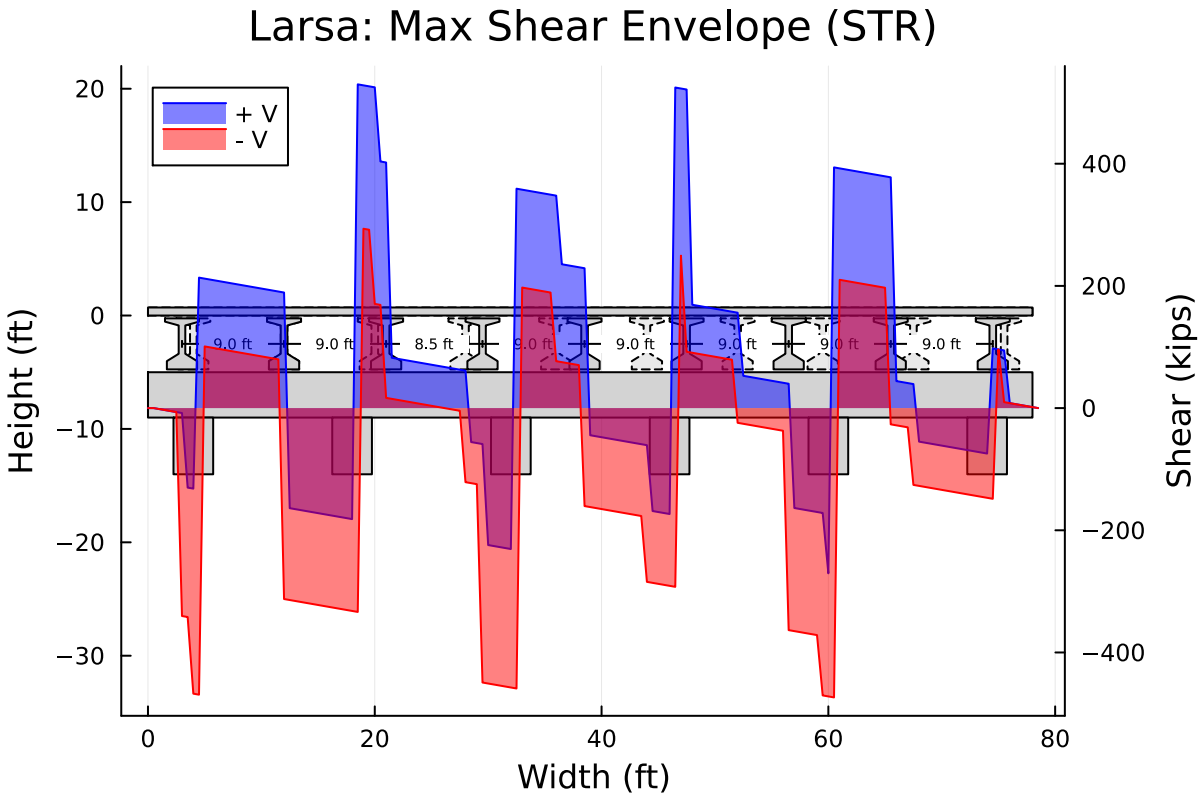

Figure 4.13: LARSA: Strength Shear Envelope Diagram

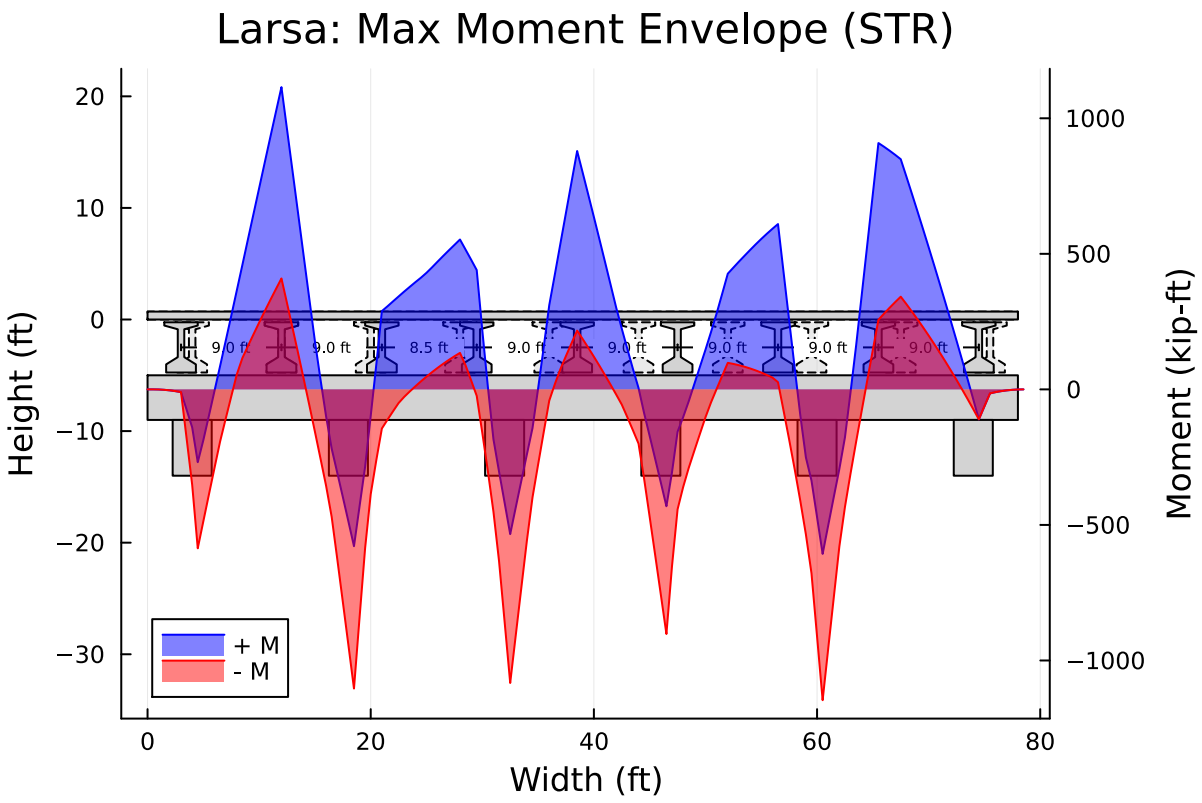

Figure 4.14: LARSA: Strength Moment Envelope Diagram

4.3.2.2 MAXIMUM SUPPORT REACTIONS (STR)

The maximum and minimum support reactions for the load factor case are listed in the table below.

Table 9. LARSA: Strength Reactions

Station	Distance	Max Reactions	Min Reactions
9	4.5 ft	669.094 kip	359.836 kip
37	18.5 ft	848.741 kip	478.514 kip
65	32.5 ft	809.339 kip	431.215 kip
93	46.5 ft	807.774 kip	426.186 kip
121	60.5 ft	852.34 kip	483.67 kip
149	74.5 ft	628.815 kip	334.667 kip

4.4 Comparison

Below is a comparison of the Cap18 and Larsa results. Stresses were found to be fairly similar between the different programs. The main differences are in the shear stresses. Cap18 seems to have a more gradual change in shear compared to Larsa. This is most likely due to the way Cap18 defines the point loads in the program. This gradual vs more sharp change in shear does not seem to affect the moment diagram in a significant way. Moment diagram stresses do show some differences and will be discussed in more detail below.

Important Plot Information

The comparison plots for the shear and moment diagrams are shown below for all the different load cases. The Cap18 results are shown in a blue line and the larsa results are shown in a red line. The red line will only really be visible when the larsa results are greater in magnitude than the cap18 results. The thickness of the red or blue line shows how much greater in magnitdue the respective result was. The absolute difference between larsa and cap18 is show in yellow. Any positive yellow results indicate that larsa was greater in magnitude. Data labels are also visible for the moment diagrams at the local extrema. Text in blue indicates that Cap18 was greater in magnitude, while red text indicates larsa results were greater in magnitude.

4.4.1 SRV

4.4.1.1 DEAD LOAD RESULTS (SRV)

The figures below compare the DL results between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment and shears, the results are within 3%.

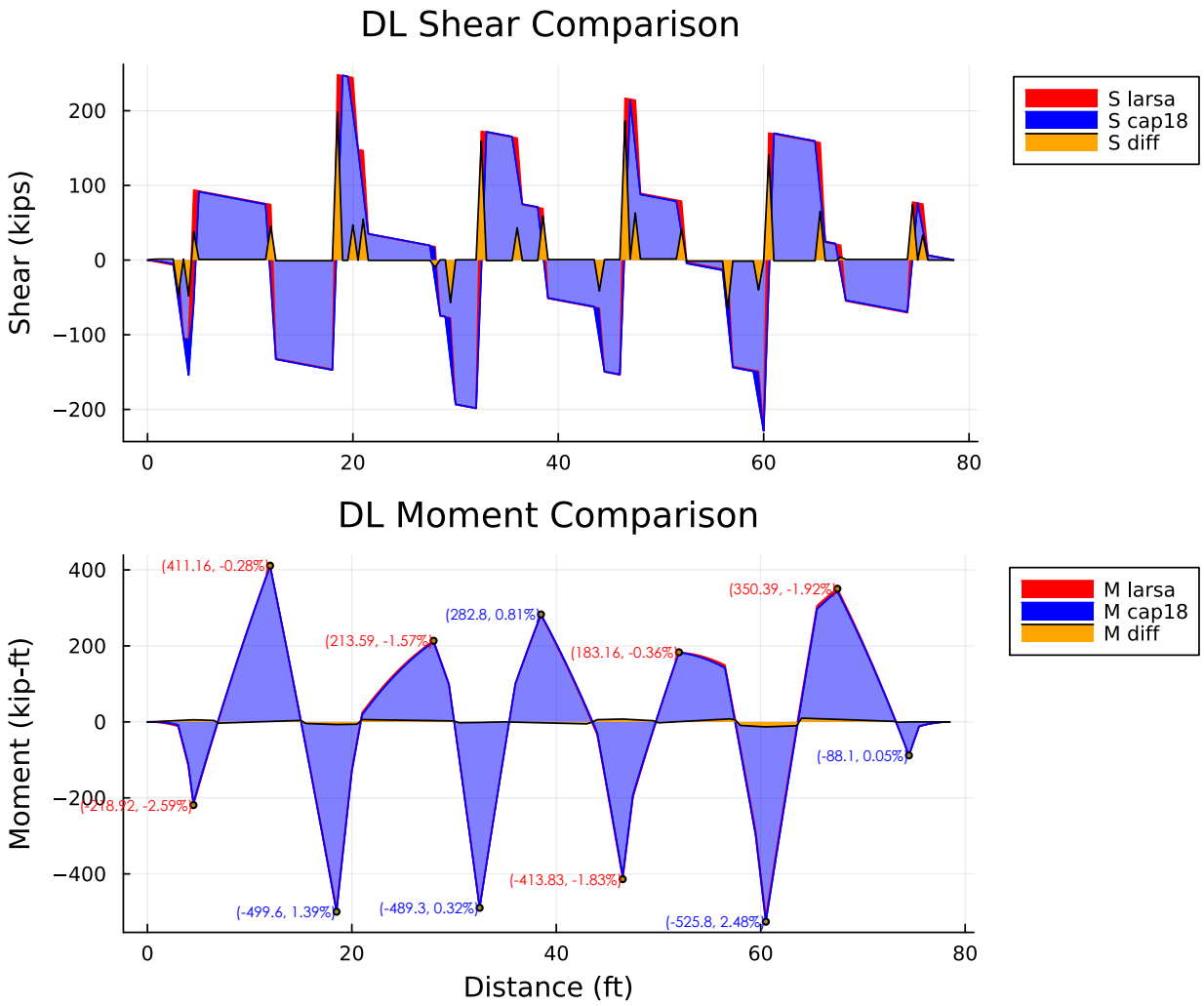

Figure 4.15: Comparison: DL Shear and Moment Diagrams

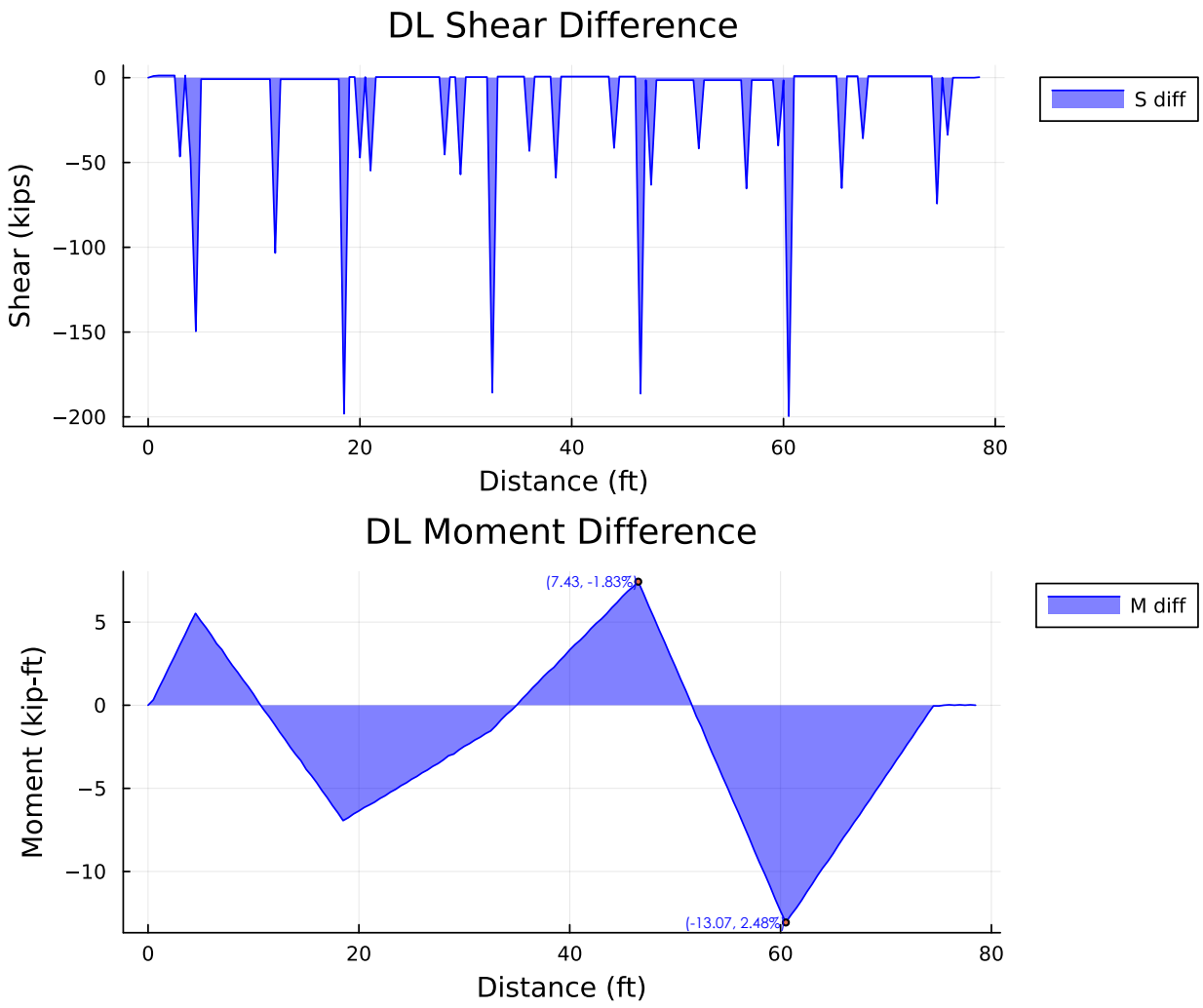

Figure 4.16: Comparison: DL Shear and Moment Difference

4.4.1.2 ENVELOPES OF MAXIMUM VALUES (SRV)

4.4.1.2.1 Maximum Envelope Comparison

The figures below compare the working stress results for the maximum stress envelope between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment and shears, the results are within 3%.

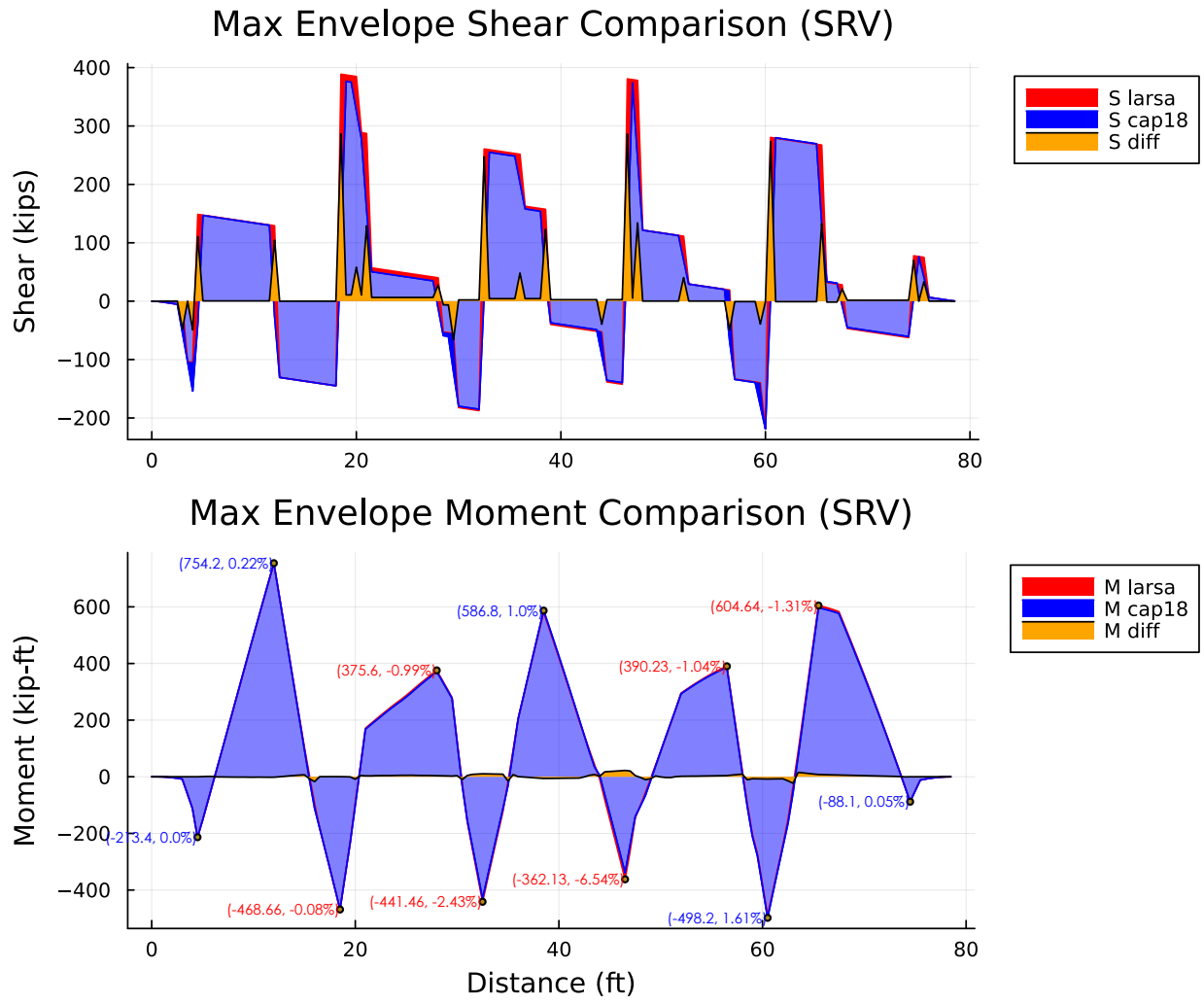

Figure 4.17: Comparison: Service Shear and Moment Max Envelope Diagrams

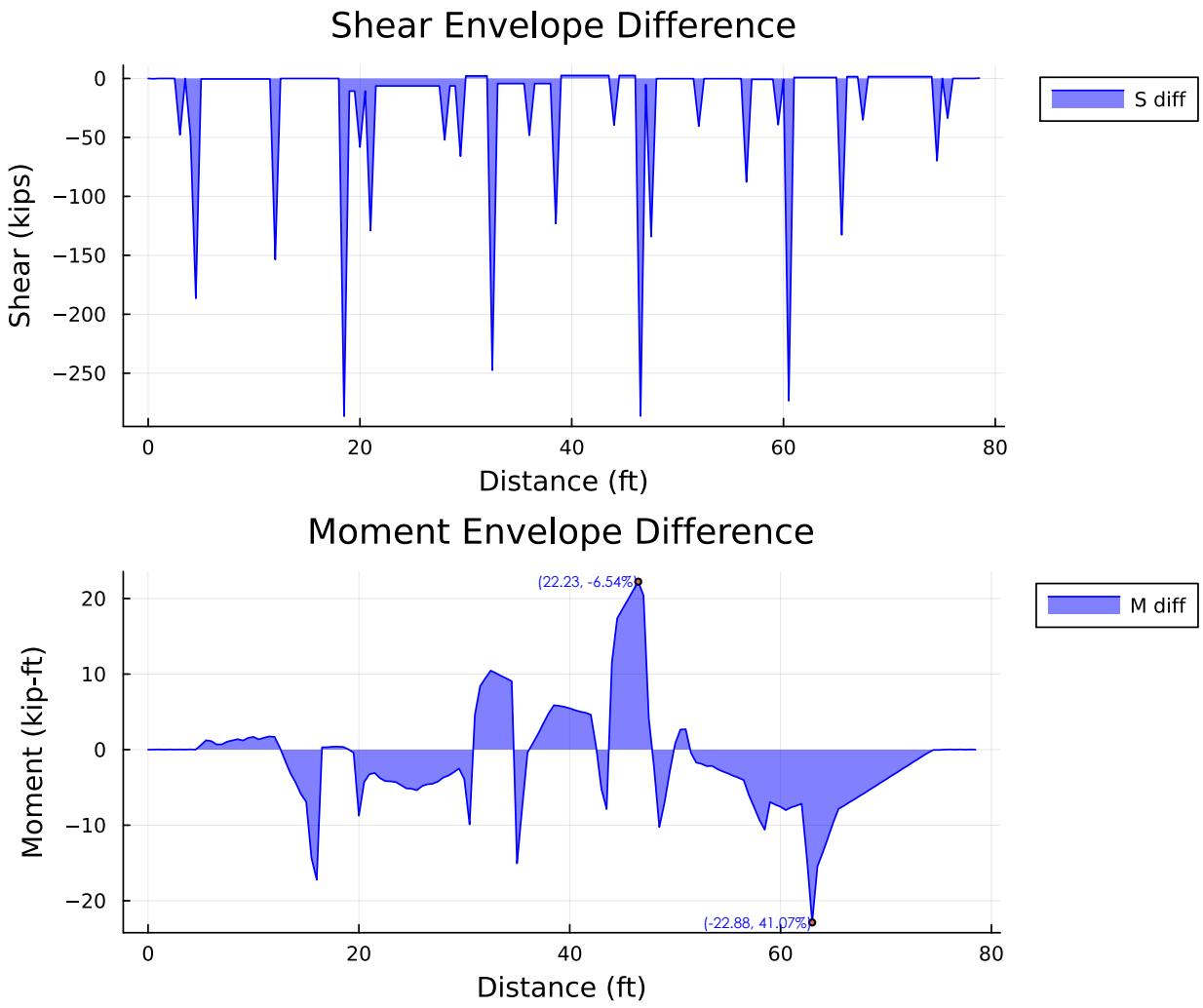

Figure 4.18: Comparison: Service Shear and Moment Max Envelope Difference

4.4.1.2.2 Minimum Envelope Comparison

The figures below compare the working stress results for the minimum stress envelope between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. . In areas of maximum moment and shears, the results are within 4%.

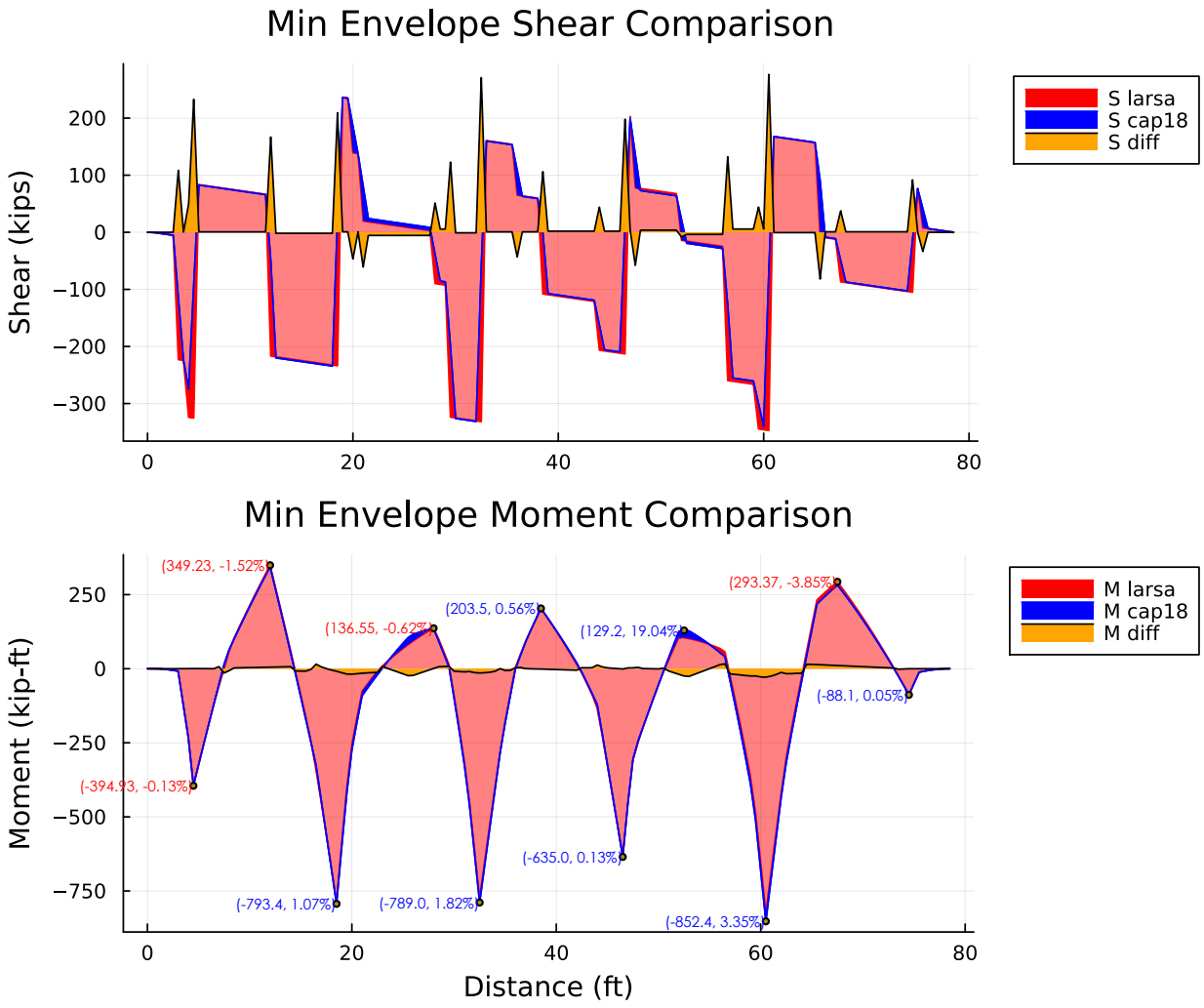

Figure 4.19: Comparison: Service Shear and Moment Min Envelope Diagrams

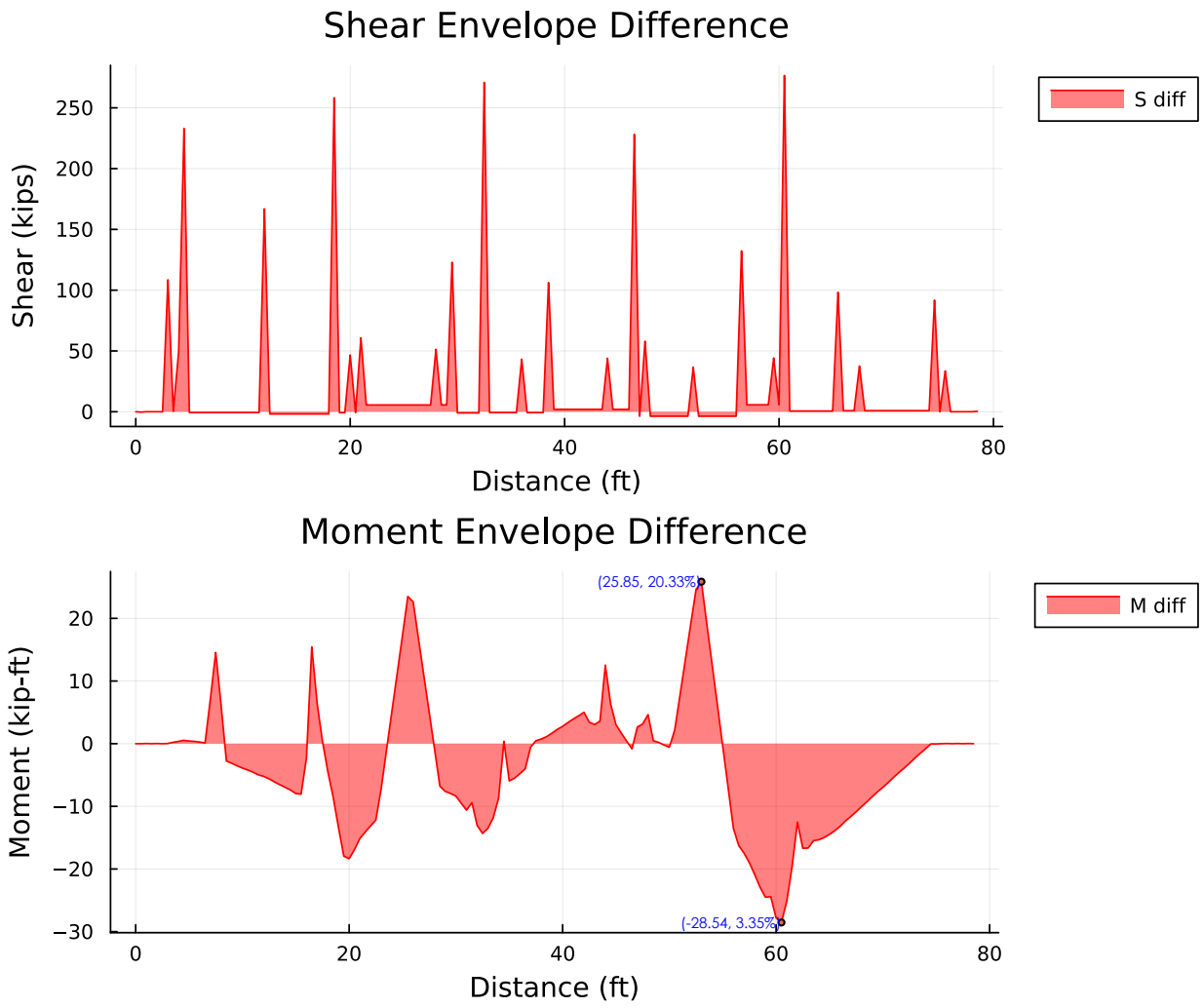

Figure 4.20: Comparison: Service Shear and Moment Min Envelope Difference

4.4.1.3 LIVE LOAD COMPARISON (SRV)

The figures below compare the working stress results for the maximum stress envelope of the live load between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, some of the differences can be explained by the difference in point load modeling between the two programs. The other shear areas where larsa results look to be higher in magnitude could potentially be explained by the difference in how the programs run the live load. The Larsa modeling of the live load is a little limited and conservative methods were used.

The maximum moment values are shown to be very similar. In areas of maximum moment, the results are within 3%.

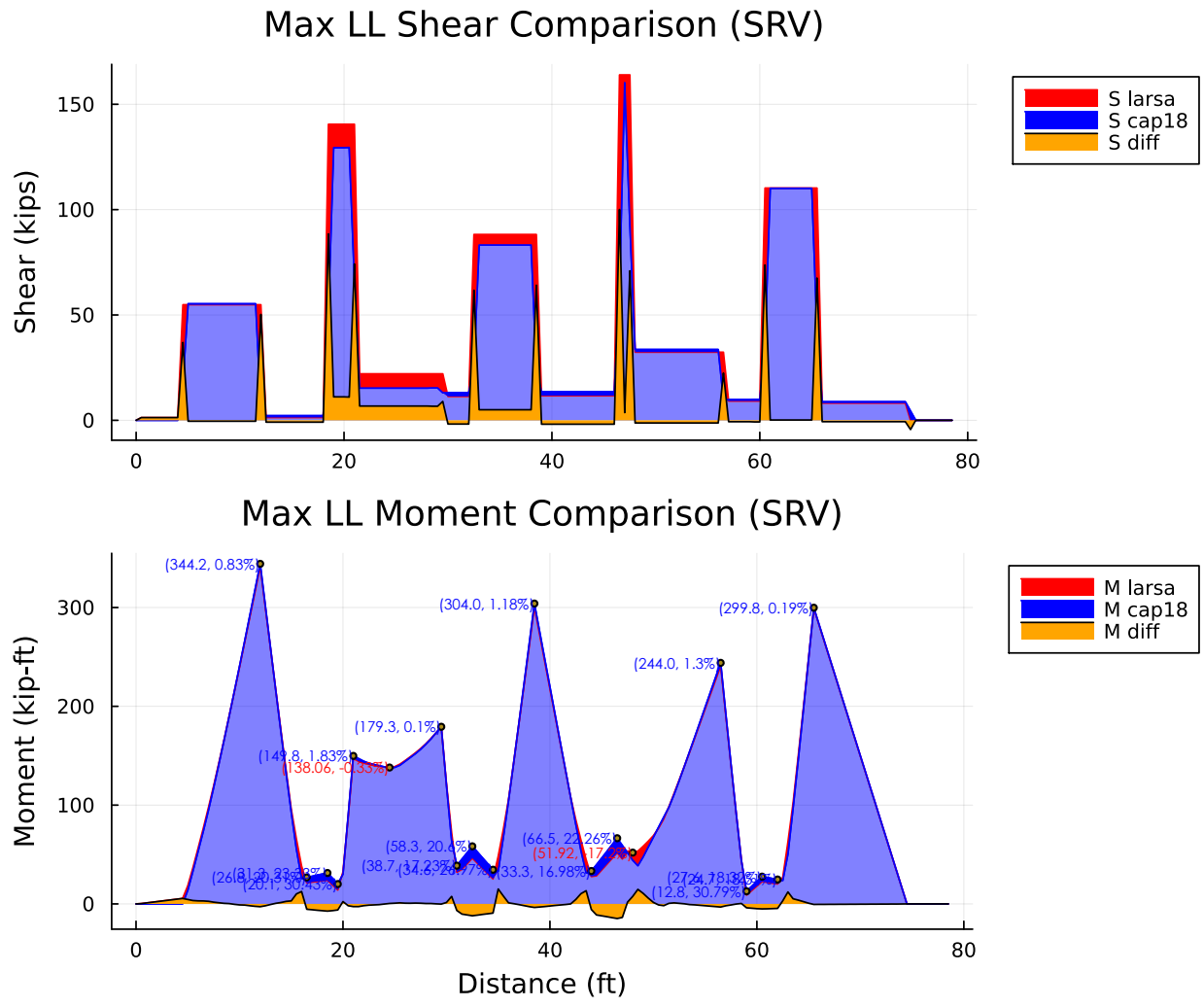

Figure 4.21: Comparison: Service Shear and Moment Max LL Envelope Diagrams

The figures below compare the working stress results for the minimum stress envelope of the live load between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. There are also large red spikes in the shear diagram for the larsa results. This is also a sign there are some unrealistic modeling behaviors in the larsa model.

The maximum moment values are shown to be very similar. In areas of maximum moment, the results are within 5%.

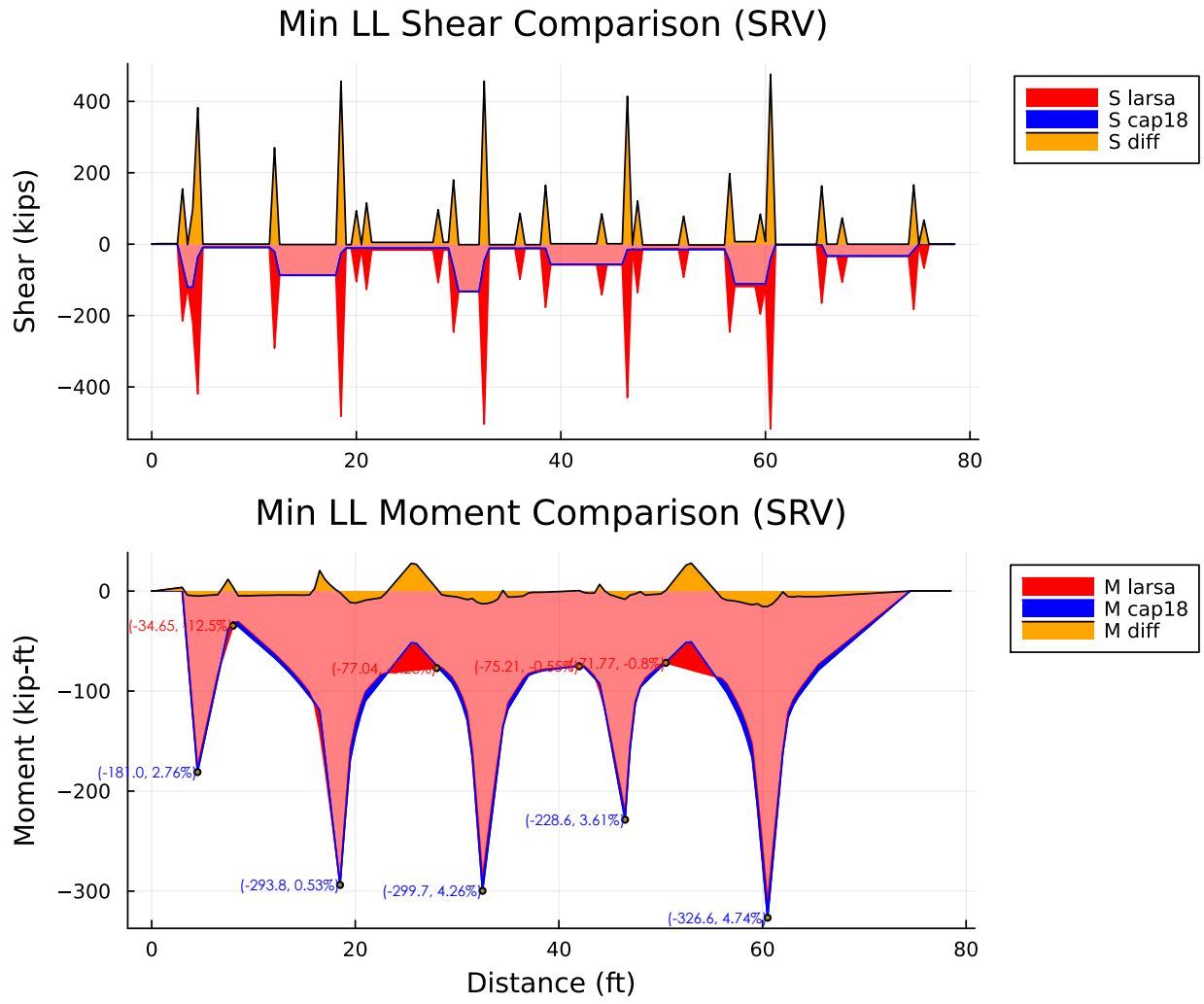

Figure 4.22: Comparison: Service Shear and Moment Min LL Envelope Diagrams

4.4.1.4 MAXIMUM SUPPORT REACTIONS (SRV)

The figure below compares the working stress results for the maximum and minimum reactions between the two programs. The results between programs are within 2% of eachother.

Figure 4.23: Comparison: Service Reactions

4.4.2 STR

4.4.2.1 ENVELOPES OF MAXIMUM VALUES (STR)

The figures below compare the load factor results for the maximum stress envelope between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment, the results are within 3%.

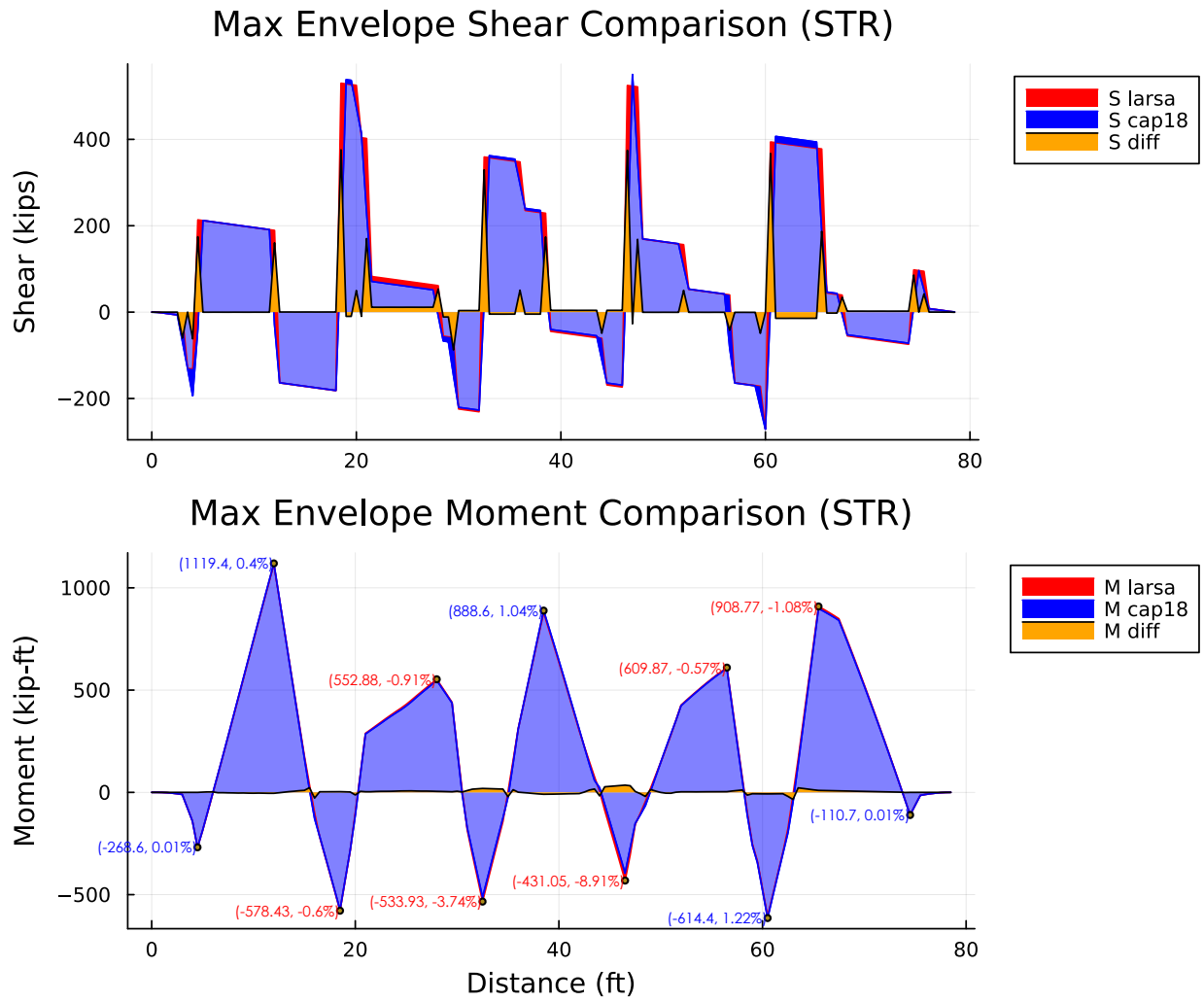

Figure 4.24: Comparison: Strength Shear and Moment Max Envelope Diagrams

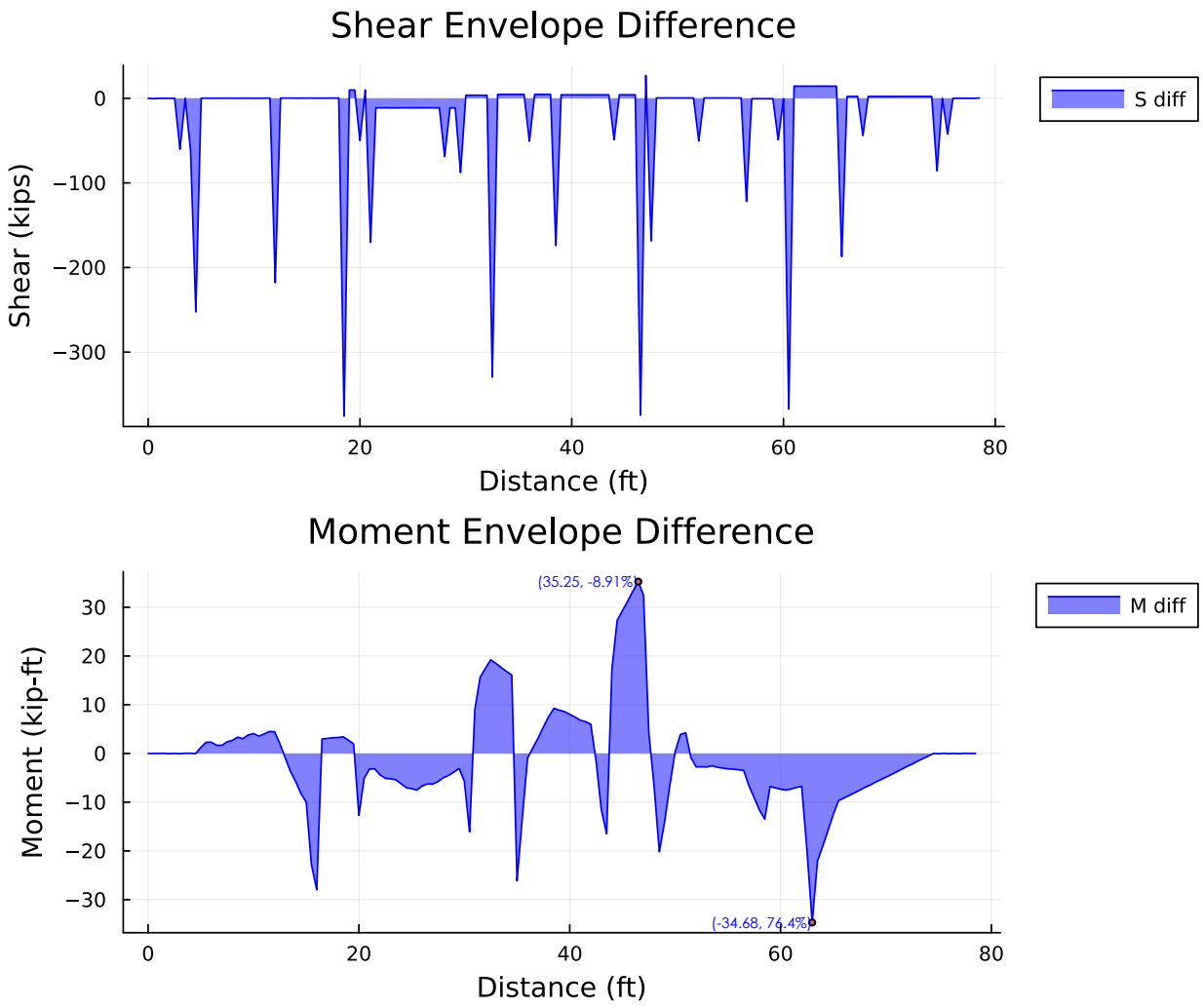

Figure 4.25: Comparison: Strength Shear and Moment Max Envelope Difference

The figures below compare the load factor results for the minimum stress envelope between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. . In areas of maximum moment and shears, the results are within 8%. Areas where larsa results are greater than cap18 are within 5% (these areas are also positive moments when negative moment are being maximized).

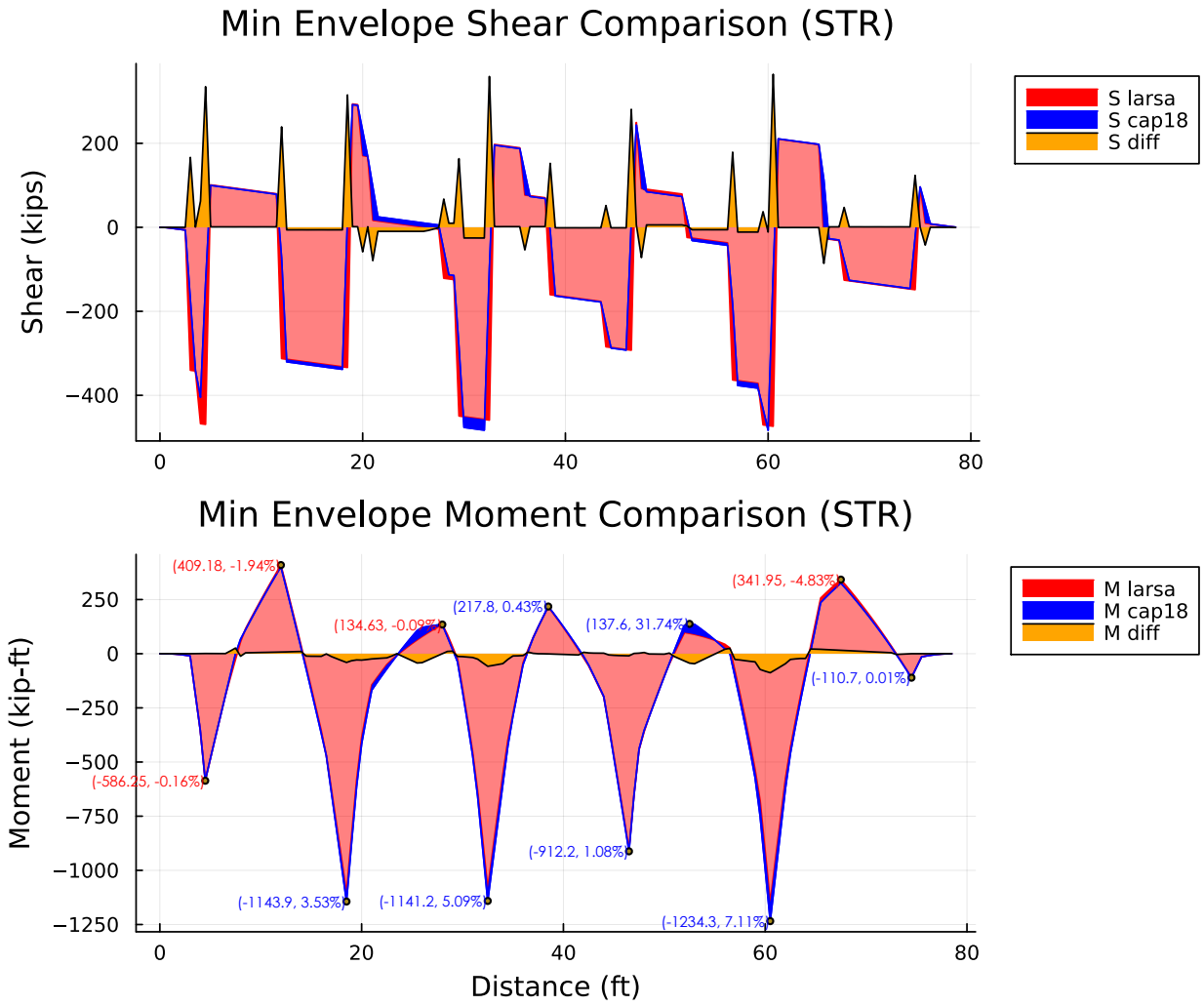

Figure 4.26: Comparison: Strength Shear and Moment Min LL Envelope Diagrams

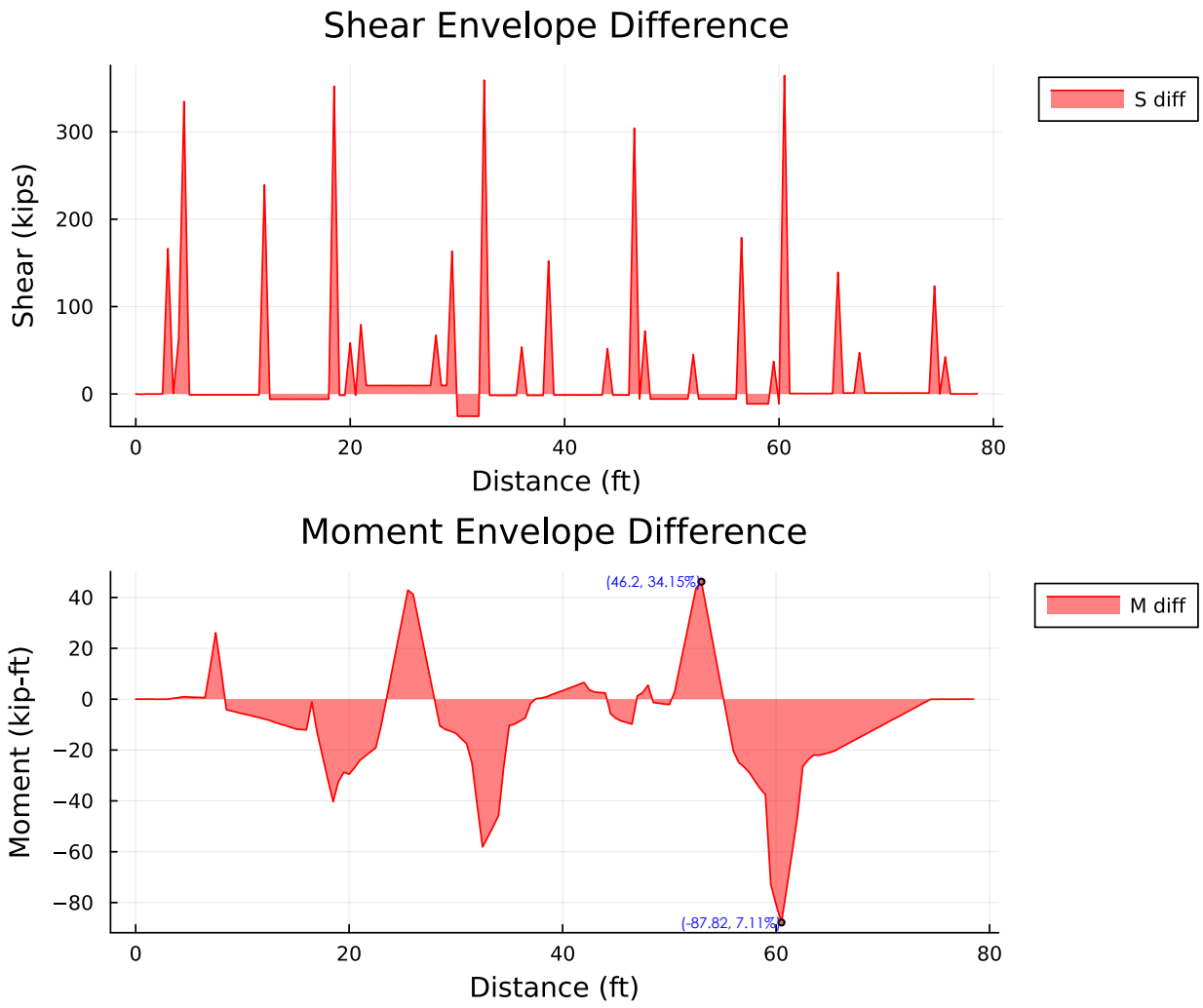

Figure 4.27: Comparison: Strength Shear and Moment Min Envelope Difference

4.4.2.2 LIVE LOAD COMPARISON (STR)

The figures below compare the load factor results for the maximum stress envelope of the live load between the two programs. The areas in red highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. The maximum values are shown to be very similar. In areas of maximum moment, the results are within 3% (when looking at the positive moments).

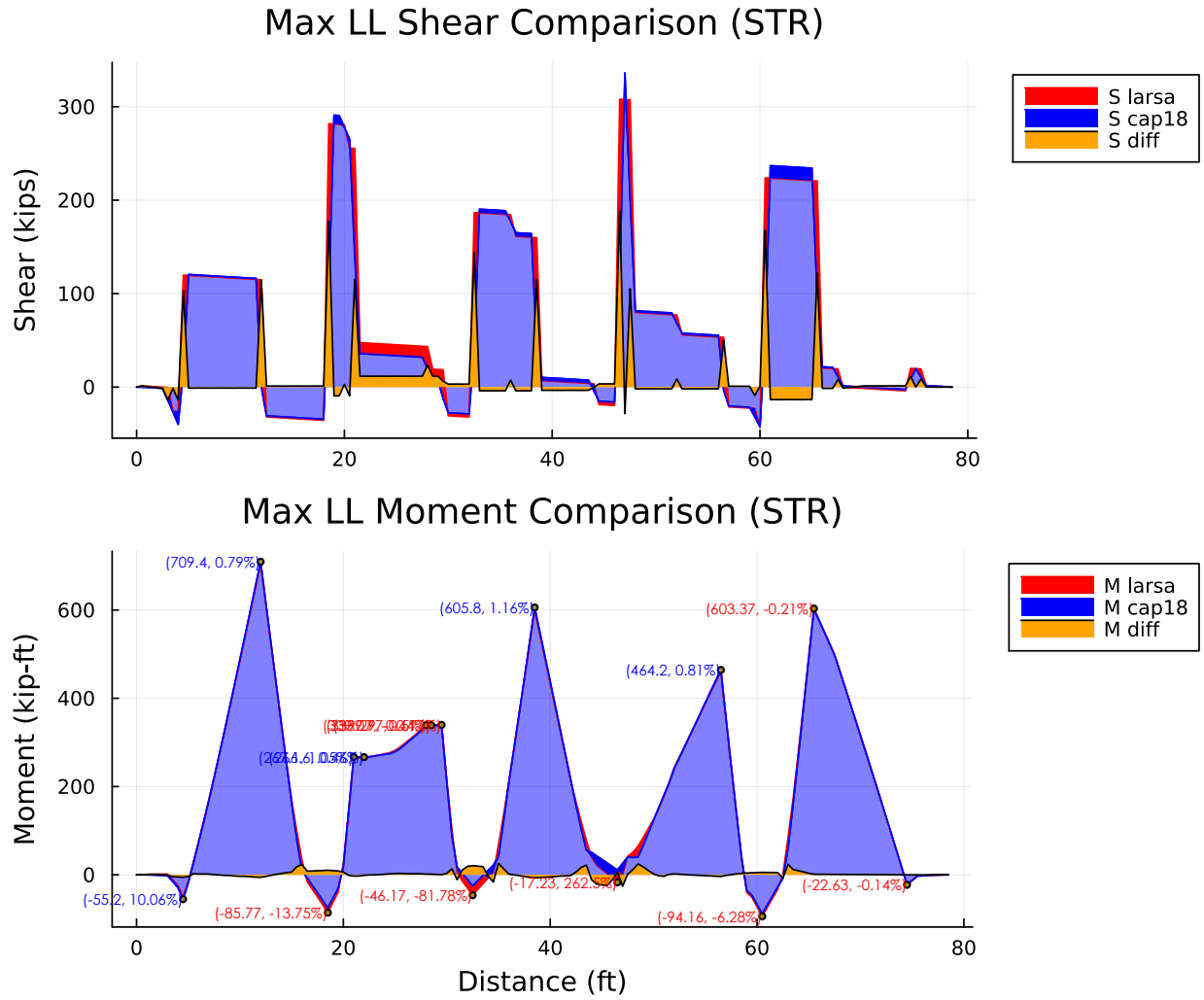

Figure 4.28: Comparison: Strength Shear and Moment Max LL Envelope Diagrams

The figures below compare the load factor results for the minimum stress envelope of the live load between the two programs. The areas in red (not the light red areas) highlight where larsa results were greater in magnitude than the cap18 results. There are some visible red areas in the shear diagram. However, these can be explained by the difference in point load modeling between the two programs. There are also large red spikes in the shear diagram for the larsa results. This is also a sign there are some unrealistic modeling behaviors in the larsa model.

The maximum moment values are shown to be very similar. In areas of maximum moment, the results are greater at 11%. However, with the limitations of the larsa model, this is not alarming. Cap18 results are higher and the program is doing a better job at maximizing the controlling areas.

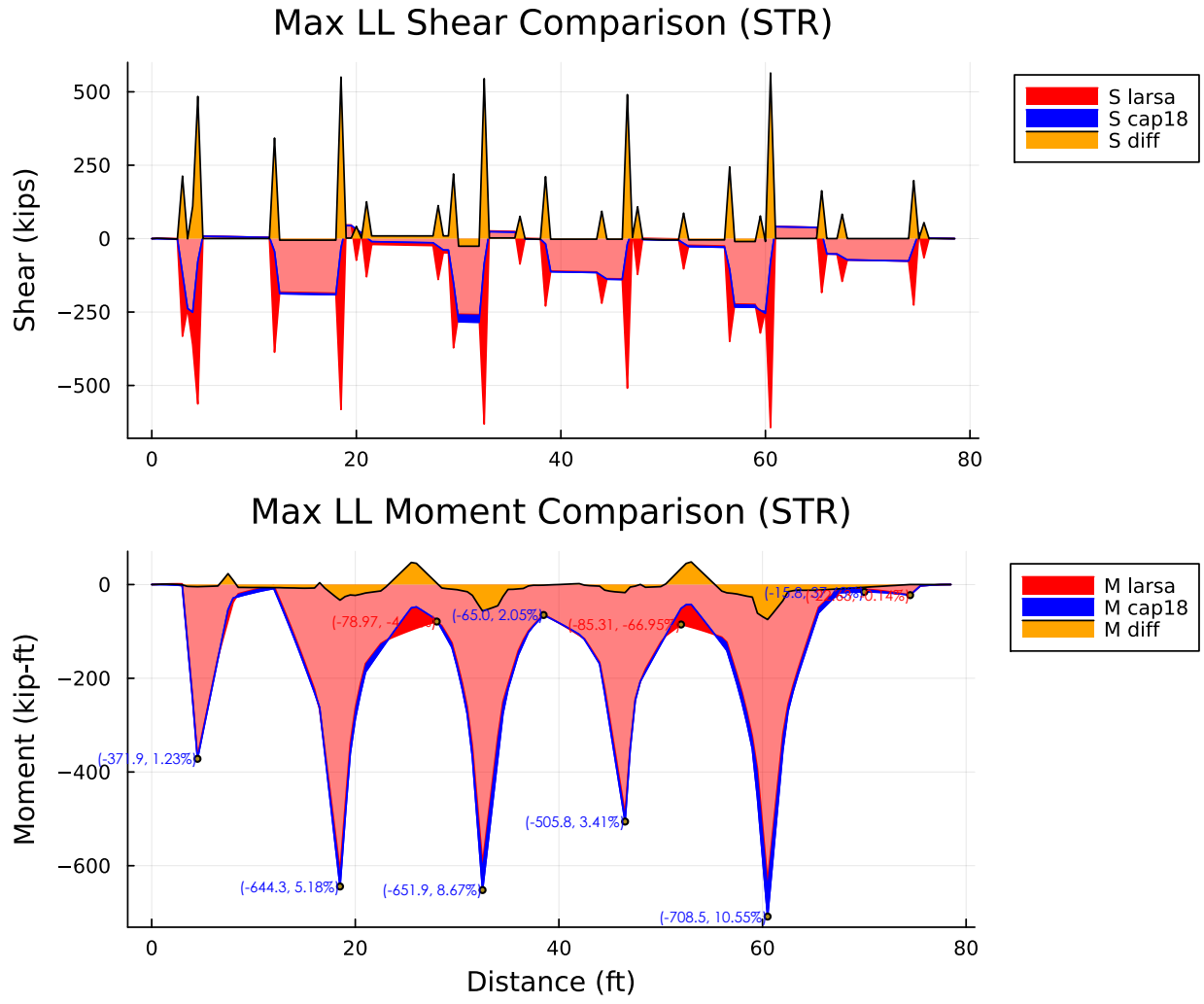

Figure 4.29: Comparison: Strength Shear and Moment Min LL Envelope Diagrams

4.4.2.3 MAXIMUM SUPPORT REACTIONS (STR)

The figure below compares the load factor results for the maximum and minimum reactions between the two programs. The results between programs are within 5% of eachother.

Figure 4.30: Comparison: Strength Reactions