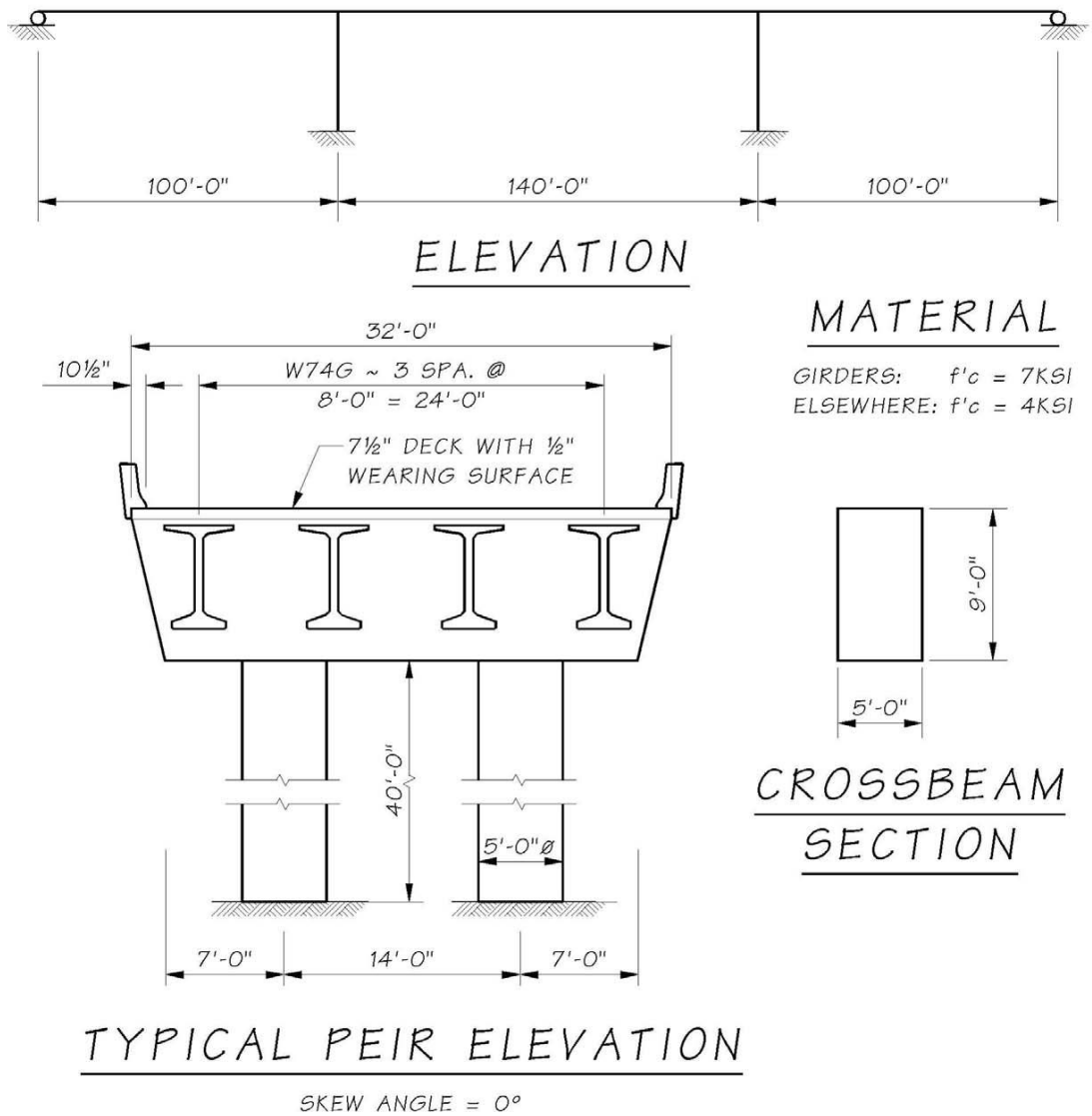
Appendix 3-B-1 HL 93 Loading for Bridge Piers

1. Introduction

The purpose of this example is to demonstrate a methodology of analyzing a bridge pier for the HL-93 live load on two-dimension plane frame in both longitudinal and transverse directions. First, the longitudinal analysis of the superstructure is analyzed. This analysis produces the live load reactions at the intermediate piers. Then the reactions are applied in the transverse direction, for the crossbeam and column design.

2. Bridge Description



3. Analysis Goals

To determine:

- Maximum axial forces and corresponding moments.
- Maximum moments and corresponding axial forces.
- Maximum shears.

4. Material Properties

4.1 Girders

$$E_c = 33{,}000 w_c^{1.5} \sqrt{f'_c}$$

$w_c = 0.160\ kcf$

$f'_c = 7\ ksi$

$E_c = 33{,}000(0.160)^{1.5} \sqrt{7} = 5588$ ksi

4.2 Slab, Columns, and Cross Beam

$w_c = 0.160\ kcf$

$f'_c = 4\ ksi$

$E_c = 33{,}000(0.160)^{1.5} \sqrt{4} = 4224$ ksi

5. Section Properties

Compute the geometric properties of the girder, columns, and cap beam.

5.1 Girder

The composite girder section properties can be obtained from the Section Properties Calculator in QConBridge program for the longitudinal direction.

$A = 1254.6\ in^2$

$I = 1{,}007{,}880\ in^3$

5.2 Column

Section properties of an individual column are obtained by simple formula for longitudinal and transverse directions:

$$A = \pi \frac{d^2}{4} = \pi \frac{\left(5\,ft \cdot 12\,\frac{in}{ft}\right)^2}{4} = 2827\ in^2$$

$$I = \pi \frac{d^4}{64} = \pi \frac{\left(5\,ft \cdot 12\,\frac{in}{ft}\right)^4}{64} = 636{,}172\ in^4$$

For the longitudinal analysis we need to proportion the column stiffness to each girder line. For longitudinal analysis the section properties of the each column member are:

$$A = \frac{(2\ columns) * (2827\ in^2\ per\ column)}{4\ girder\ lines} = 1413\ in^2$$

$$I = \frac{(2\ columns) * (636{,}172\ in^4\ per\ column)}{4\ girder\ lines} = 318{,}086\ in^4$$

NOTE

For other column shapes and columns on a skewed bent, the properties of the columns need to be computed in the plane of the longitudinal and transverse frames respectively for analysis in each direction.

5.3 Cap Beam

Cap beam properties are obtained by simple formula in transverse direction:

$$A = w \cdot h = 5\,ft \cdot 9\,ft \cdot 144\,\tfrac{in^2}{ft^2} = 6480\ in^2$$

$$I = \frac{1}{12} w \cdot h^3 = \frac{1}{12} \cdot 5\,ft \cdot (9\,ft)^3 \cdot 20736\,\tfrac{in^4}{ft^4} = 6{,}298{,}560\ in^4$$

6. Longitudinal Analysis

The purpose of this analysis is to determine the maximum live load reactions that will be applied to the bent. The results from this analysis will be scaled by the number of loaded lanes causing maximum responses in the bent and distributed to individual columns, for the transverse analysis.

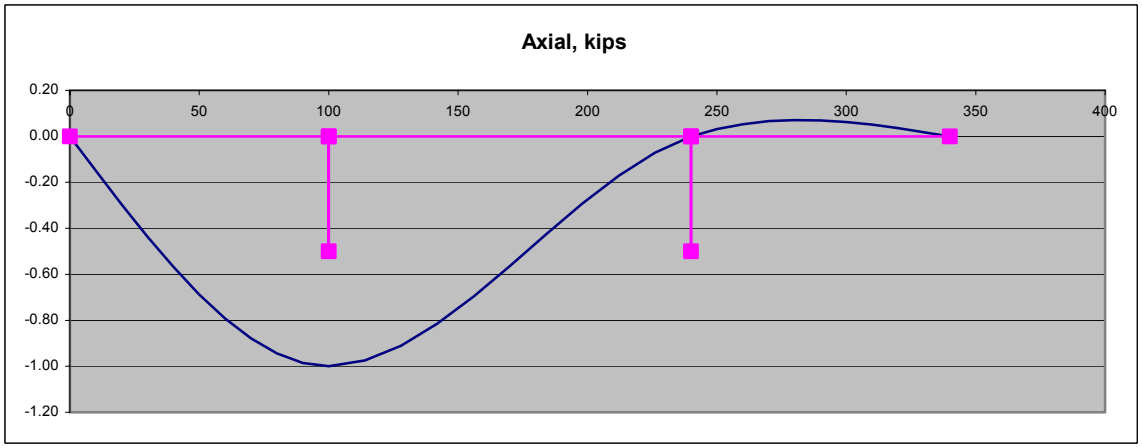
The longitudinal analysis consists of applying various combinations of design lane and design trucks. The details can be found in AAHSTO LRFD 3.6.

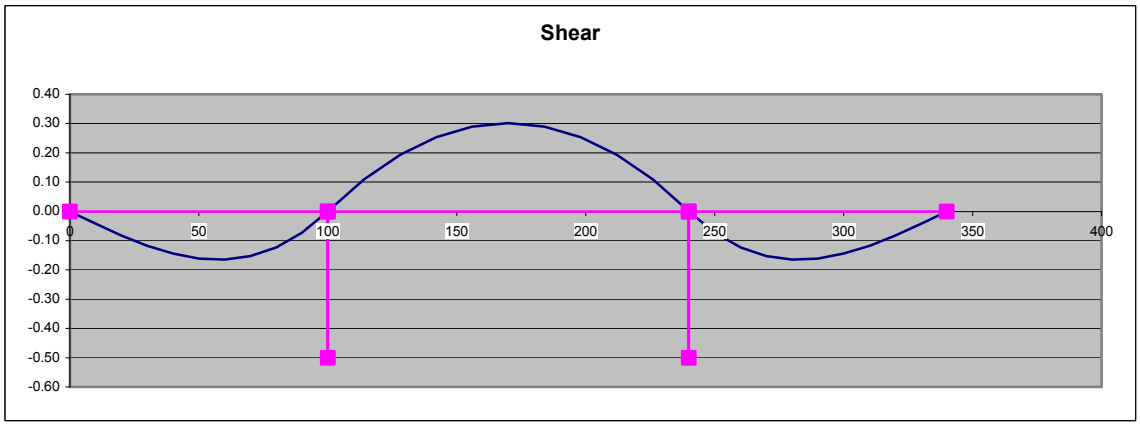
6.1 Loading

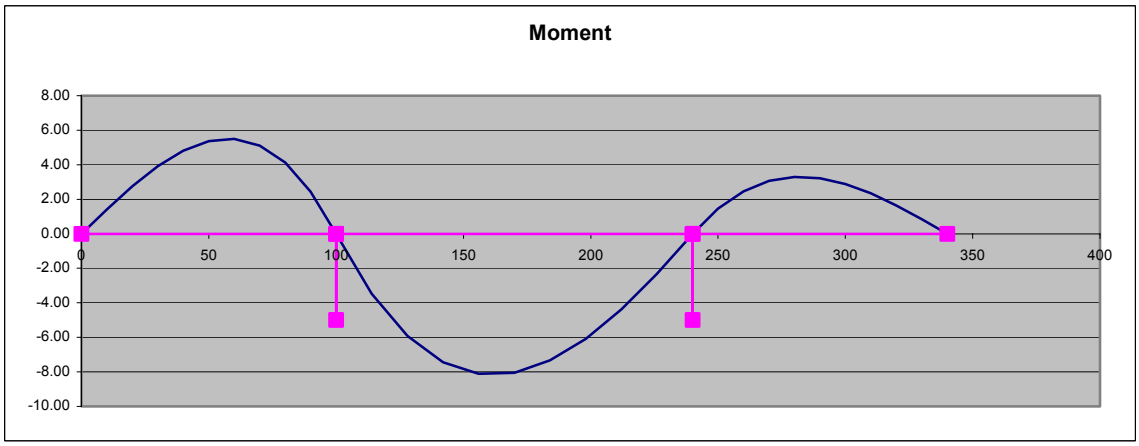
In order to produce the maximum moment and reaction at interior piers, two trucks spaced at 50 feet minimum are used in the longitudinal direction per AASHTO LRFD Section 3.6.1.3. The influence lines of the axial force, moment, and shear at the top and bottom column of the live loading show the effect of a two-truck loading.

6.1.1 Influence Lines

Figures below are influence lines for axial force, shear, and moment at the top of Pier 2 for a unit load moving along a girder line. The influence lines for the bottom of the pier will be exactly the same, except the moment influence will be different by an amount equal to the shear times the pier height.


Axial, kips
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
0
50
100
150
200
250
300
350
400


Shear
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
0
50
100
150
200
250
300
350
400


Moment
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0
50
100
150
200
250
300
350
400

To achieve the maximum compressive reaction, the lane load needs to be in spans 1 and 2, and the two trucks need to straddle between pier 2 and be as close to each other as possible. That is, the minimum headway spacing of 50 feet will maximize the axial reaction.

Maximum shears and moments occur under two conditions. First, spans 1 and 3 are loaded with the lane load and the two truck loading. The headway spacing that causes the maximum response is in the range of 180 – 200 feet. Then, a span 2 is loaded with the lane load and the two truck train. The headway spacing is at its minimum value of 50 ft.

Analytically finding the exact location and headway spacing of the trucks for the extreme force effects is possible, but hardly worth the effort. Structural analysis tools with a moving load generator, such as GTSTRUDL, can be used to quickly determine the maximum force effects.

6.2 Results

A longitudinal analysis is performed using GTSTRUDL. The details of this analysis are shown.

The result of the longitudinal analysis consists of two-truck train and lane load results. These results need to be combined to produce the complete live load response. The complete response is computed as $Q_{LL+IM} = 0.9[(IM)(Dual\ Truck\ Train) + Lane\ Load]$.

The dynamic load allowance (impact factor) is given by the LRFD specifications as 33%. Note that the dynamic load allowance need not be applied to foundation components entirely below ground level. This causes us to combine the two truck train and lane responses for cross beams and columns differently than for footings, piles, and shafts.

6.2.1 Combined Live Load Response

The tables below summarize the combined live load response. The controlling load cases are given in parentheses.

Maximum Axial

		Top of Pier	Bottom of Pier
	Axial (kips/lane)	Corresponding Moment (k-ft/lane)	Corresponding Moment (k-ft/lane)
Two-Truck Train	-117.9 (Loading case 1014)	-146.2	103.4
Lane Load	-89.1 (Loading case LS12)	-195.5	141.9
LL+IM (Column)	-221.3	-350.9	251.5
LL (Footing)	-186.3	N/A	220.8

Maximum Moment – Top of Pier

	Moment (k-ft/lane)	Corresponding Axial (kips/lane)
Two-Truck Train	-582.5 (Loading 1018)	-85.8
Lane Load	-364.2 (Loading LS2)	-49.4
LL+IM (Column)	-1025.0	-147.2

Maximum Moment – Bottom of Pier

	Moment (k-ft/lane)	Corresponding Axial (kips/lane)
Two-Truck Train	287.7 (Loading 1018)	-85.8
Lane Load	179.7 (Loading LS2)	-49.4
LL+IM (Column)	506.1	-147.2
LL+IM (Footing)	420.7	-121.7

Maximum Shear

	Shear (kips/lane)
Two-Truck Train	21.8 (Loading 1018)
Lane Load	13.6 (Loading LS2)
LL+IM (Column)	38.3
LL (Footing)	31.9

7. *Transverse Analysis*

Now that we have the maximum lane reactions from the longitudinal girder line analysis, we need to apply these as loads to the bent frame.

7.1 *Loading*

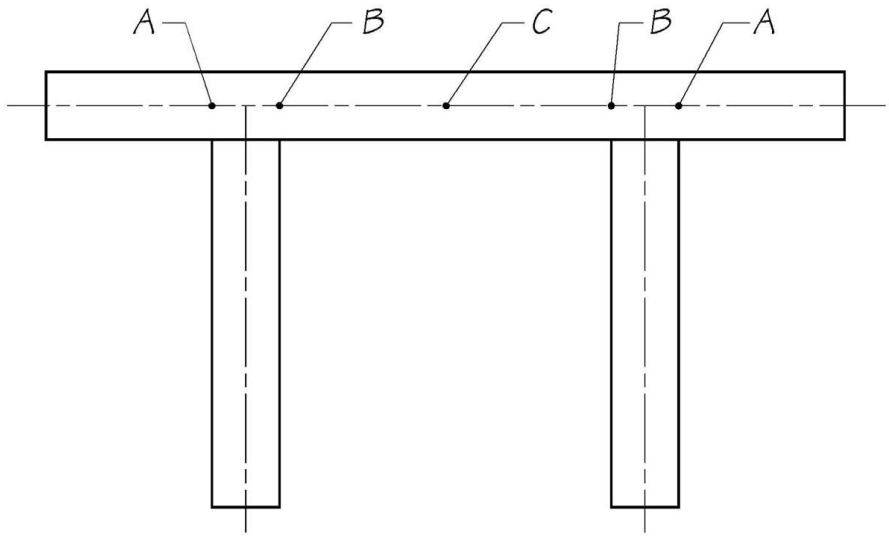
Apply the superstructure live load reactions of the longitudinal direction to substructure by placing the wheel line reactions directly to the crossbeam and varying the number and position of design lanes described in chapter 7 of the BDM.

7.2 *Results*

A transverse analysis is performed using GTSTRUDL. The details of this analysis are shown.

7.2.1 *Cap Beam*

For this example, we will look at results for three design points, the left and right face of the left-hand column, and at the mid-span of the cap beam. Note that in the analysis, the wheel line reactions were applied from the left hand side of the bent. This does not result in a symmetrical set of loadings. However, because this is a symmetrical frame we expect symmetrical results. The controlling results from the left and right hand points “A” and “B” are used.



For shear design of the crossbeam, LRFD specifications section C5.8.3.4.2 allows determination of the effects for moments and shears on the capacity of a section using the maximum factored moments and shears at the section. Hence, the results below do not show the maximum shears and corresponding moments.

The tables below summarize the results of the transverse analysis for the crossbeam. The basic results are adjusted with the multiple presence factors per LRFD Table 3.6.1.1.2-1. The controlling load cases are in parentheses.

Point A

	Shear (kips)	+Moment (k-ft)	-Moment (k-ft)
Force Effect	110.7 (Loading 1009)	0	-484.3 (1029)
Multiple Presence Factor	1.2	1.2	1.2
LL+IM	132.8	0	-581.2

Point B

	Shear (kips)	+Moment (k-ft)	-Moment (k-ft)
Force Effect	155.8 (Loading 2330)	314.3 (Loading 1522)	-650.9 (Loading 1029)
Multiple Presence Factor	1.0	1.2	1.2
LL+IM	155.8	377.2	-781.1

Point C

	Shear (kips)	+Moment (k-ft)	-Moment (k-ft)
Force Effect	87.9 (Loading 2036)	426.4 (Loading 1520)	-400.5 (Loading 1029)
Multiple Presence Factor	1.0	1.2	1.2
LL+IM	87.9	511.7	-480.6

7.2.2 Columns

The tables below show the live load results at the top and bottom of a column. The results are factored with the appropriate multiple presence factors. The controlling load cases are in parentheses.

Maximum Axial – Top and Bottom of Column

		Top of Column	Bottom of Column
	Axial (kips)	Corresponding Moment (k-ft)	Corresponding Moment (k-ft)
Force Effect	-347.6 (Loading 2026)	34.1	28.4
Multiple Presence Factor	1.0	1.0	1.0
LL+IM	-347.6	34.1	28.4

Maximum Moment – Top of Column

	Moment (k-ft)	Corresponding Axial (kips)
Force Effect	59.3 (Loading 1009)	-265.6
Multiple Presence Factor	1.2	1.2
LL+IM	71.2	-318.7

Maximum Moment – Bottom of Column

	Moment (k-ft)	Corresponding Axial (kips)
Force Effect	-53.6 (Loading 1029)	55.6
Multiple Presence Factor	1.2	1.2
LL+IM	-64.3	66.7

Maximum Shear

	Shear (kips)
Force Effect	-1.0 (Loading 1029)
Multiple Presence Factor	1.2
LL+IM	-1.2

7.2.3 Footings

In obtaining the footing forces of the loads from the analysis above, the linear elastic system, the principle of superposition can be used. The footing results are simply the column results scaled by the ratio of the footing load to the column load. For this case, the scale factor is 186.3÷221.3 = 0.84.

Maximum Axial – Top of Footing

	Axial (kips)	Corresponding Moment (k-ft)
LL	-292	23.9

Maximum Moment – Top of Footing

	Moment (k-ft)	Corresponding Axial (kips)
LL	-45.0	46.7

Maximum Shear – Top of Footing

	Shear (kps)
LL	-1.0

8. *Combining Longitudinal and Transverse Results*

To get the full set of column forces, the results from the longitudinal and transverse analyses need to be combined. Recall that the longitudinal analysis produced moments, shears, and axial load for a single loaded lane whereas the transverse analysis produced column and footing forces for multiple loaded lanes.

Before we can combine the force effects we need to determine the per column force effect from the longitudinal analysis. To do this, we look at the axial force results in transverse model to determine the lane fraction that is applied to each column.

For maximum axial load, 2 lanes at 221.3 kips/lane produce an axial force of 347.6 kips. The lane fraction carried by the column is 347.6/(2*221.3) = 0.785 (78.5%).

Mz = (-350.9 K-FT/LANE)(2 LANES)(0.785)(1.0) = -550.9 K-FT (Top of Column)

Mz = (251.5 K-FT/LANE)(2 LANES)(0.785)(1.0) = 394.9 K-FT (Bottom of Column)

Mz = (220.8 K-FT/LANE)(2 LANES)(0.785)(1.0) = 346.7 K-FT (Footing)

For maximum moment (and shear because the same loading governs) at the top of the column, 1 lane at 221.3 kips/lane produces an axial force of 318.7 kips (318.7/221.3 = 1.44), 144% of the lane reaction is carried by the column.

Mz = (-1025.0)(1.44)(1.2) = -1771.2 k-ft

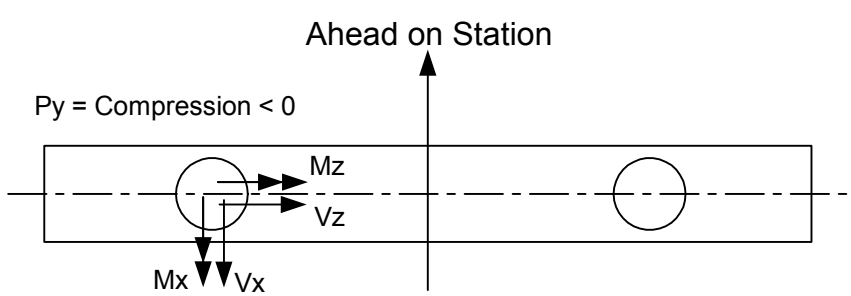
Vx = (38.3)(1.44)(1.2) = 66.2 K (Column)

Vx = (31.9)(1.44)(1.2) = 55.1 K (Footing)

For maximum moment at the bottom of the column, 1 lane at 221.3 kips/lane produces an axial force of 66.7 kips (66.7/221.3 = 0.30) 30% of the lane reaction is carried by the column.

Mz = (506.1)(0.30)(1.2) = 182.2 k-ft (Column)

Mz = (420.7)(0.30)(1.2) = 151.4 k-ft (Footing)



Vx and Mz determined from Longitudinal Analysis
Py, Vz and Mx determined from Transverse Analysis

Column

	Load Case				
	Maximum Axial Top	Maximum Axial Bottom	Maximum Moment Top	Maximum Moment Bottom	Shear
Axial (kips)	-347.6	-347.6	- 318.7	66.7	
Mx (k-ft)	34.1	28.4	71.2	-64.3	
Mz (k-ft)	-550.9	394.9	-1771.2	182.1	
Vx (kips)					66.2
Vz (kips)					-1.2

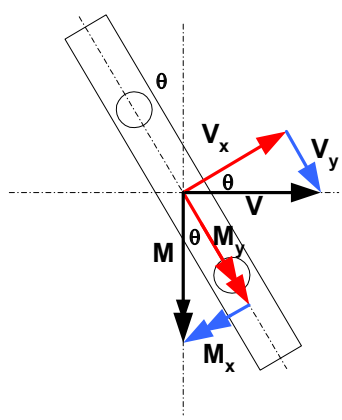
Footing

	Load Cases		
	Maximum Axial	Maximum Moment Bottom	Shear
Axial (kips)	-292	46.7	
Mx (k-ft)	23.9	-45.0	
Mz (k-ft)	346.7	151.4	
Vx (k)			72.7
Vz (k)			-1.0

9. *Skew Effects*

This analysis becomes only slightly more complicated when the pier is skewed with respect to the centerline of the bridge. The results of the longitudinal analysis need to be adjusted for skew before being applied to the transverse model.

The shears and moments produced by the longitudinal analysis are in the plane of the longitudinal model. These force vectors have components that are projected into the plane of the transverse model as show in the figure below. The transverse model loading must include these forces and moments for each wheel line load. Likewise, the skew adjusted results from the longitudinal analysis need to be used when combining results from the transverse analysis.



10. Summary

This example demonstrates a method for analyzing bridge piers subjected to the LRFD HL-93 live load.

11. Longitudinal Analysis Details

The following output shows the longitudinal analysis details. In the live load generation portion of the GTSTRUDL input, you will see multiple trials for live load analysis. Each trial uses a different range of headways spacing for the dual truck train. The first trial varies the headway spacing from 180 to 205 feet. Based on this, a tighter range between 193 and 198 feet was used to get the headway spacing corresponding to the maximum loads correct to within 1 foot.

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1GTICES/C-NP 2.5.0 MD-NT 2.0, January 1995.
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Reading password file J:\GTSTRUDL\Gtaccess26.dat
 CI-i-audfile, Command AUDIT file FILE0857.aud has been activated.

 *** G T S T R U D L ***
    RELEASE DATE          VERSION             COMPLETION NO.
    February, 2002        26.0                    4290

 **** ACTIVE UNITS -  LENGTH   WEIGHT   ANGLE    TEMPERATURE   TIME
 **** ASSUMED TO BE     INCH    POUND   RADIAN    FAHRENHEIT   SECOND


 {    1} > $ ---------------------------------------------------------
 {    2} > $ This is the Common Startup Macro; put your company-wide startup commands here.
 {    3} > $ You can edit this file from Tools -- Macros.  Click "Startup" and then "Edit".
 {    4} > $ ---------------------------------------------------------

 {    1} > CINPUT 'C:\Documents and Settings\bricer\My Documents\BDM\HL93 Live Load -
```

```
{    2} >_Analysis of Piers\Longitudinal.gti'
{    3} > $ ---------------------------------------------------------
{    4} > $ Live Load Pier Analysis Example
{    5} > $ Longitudinal Anaysis to determine maximum lane reactions
{    6} > $ ---------------------------------------------------------
{    7} > $
{    8} > STRUDL



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 *                                                                *
 *   ******                          G T S T R U D L              *
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 *  RELEASE DATE         VERSION             COMPLETION NO.       *
 *  February, 2002       26.0                    4290             *
 *                                                                *
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**** ACTIVE UNITS -  LENGTH   WEIGHT   ANGLE    TEMPERATURE   TIME
**** ASSUMED TO BE     INCH    POUND   RADIAN    FAHRENHEIT   SECOND

{    9} > TYPE PLANE FRAME XY
{   10} > OUTPUT LONG NAME
{   11} > UNITS FEET KIPS
{   12} > $
{   13} > JOINT COORDINATES
{   14} > $      Name            X coord           Y coord
```

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{   15} > $  --------       -------------       ------------
{   16} >           1             0.00000            0.00000
{   17} >           2           100.00000            0.00000
{   18} >           3           240.00000            0.00000
{   19} >           4           340.00000            0.00000
{   20} >           5           100.00000          -40.00000 S
{   21} >           6           240.00000          -40.00000 S
{   22} > $
{   23} > $
{   24} > $ ------------- Boundary conditions -------
{   25} > $ --- Roller joints: rotation + horiz. translation
{   26} > DEFINE GROUP 'roller' ADD JOINTS 1 4
{   27} > STATUS SUPPORT JOINT GROUP 'roller'
{   28} > JOINT GRP 'roller' RELEASES FORCE X MOM Z
{   29} > $
{   30} > MEMBER INCIDENCES
{   31} > $      Name  Start joint  End joint
{   32} > $  --------     --------   --------
{   33} >           1            1          2
{   34} >           2            2          3
{   35} >           3            3          4
{   36} >           4            5          2
{   37} >           5            6          3
{   38} > $
{   39} > $ ------------- Properties ----------------
{   40} > UNITS INCHES
{   41} > MEMBER PROPERTIES
{   42} >    1 TO 3 AX 1255 IZ 1007880
{   43} >    4 TO 5 AX 1413 IZ 318086
{   44} >
{   45} > CONSTANTS
{   46} >    E 5588 MEMBERS 1 TO 3
{   47} >    E 4224 MEMBERS 4 TO 5
{   48} > $
{   49} > $ ------------- Loadings ------------------
{   50} > UNITS KIP FEET
{   51} > $
{   52} > $ --- Lane Loads ---
{   53} > LOADING 'LS12' 'Load load in span 1 and 2'
{   54} > MEMBER 1 2 LOAD FORCE Y UNIFORM FRAcTIONAL -0.640 LA 0.0 LB 1.0
{   55} >
{   56} > LOADING 'LS13' 'Load load in span 1 and 3'
{   57} > MEMBER 1 3 LOAD FORCE Y UNIFORM FRAcTIONAL -0.640 LA 0.0 LB 1.0
{   58} >
{   59} > LOADING 'LS2' 'Load load in span 2'
```

```
{   60} > MEMBER 2 LOAD FORCE Y UNIFORM FRAcTIONAL -0.640 LA 0.0 LB 1.0
{   61} >
{   62} > LOADING 'LS3' 'Load load in span 3'
{   63} > MEMBER 3 LOAD FORCE Y UNIFORM FRAcTIONAL -0.640 LA 0.0 LB 1.0
{   64} >
{   65} > $ --- Dual Truck Train ---
{   66} >
{   67} > $$ --- TRIAL 1 - (GOAL: Determine approximate headway spacing)
{   68} > $$ --- RESULTS: Maximums occured for headway spacings of 50' and 205'
{   69} > $$ --- Load ID Legend
{   70} > $$ - ID = 1000 TO 1999,  50' Headway Spacing
{   71} > $$ - ID = 2000 TO 2999, 180' Headway Spacing
{   72} > $$ - ID = 3000 TO 3999, 185' Headway Spacing
{   73} > $$ - ID = 4000 TO 4999, 190' Headway Spacing
{   74} > $$ - ID = 5000 TO 5999, 195' Headway Spacing
{   75} > $$ - ID = 6000 TO 6999, 200' Headway Spacing
{   76} > $$ - ID = 7000 TO 7999, 205' Headway Spacing
{   77} > $MOVING LOAD GENERATOR
{   78} > $
{   79} > $SUPERSTRUCTURE FOR MEMBERS 1 TO 3
{   80} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0  50.0 32.0 14.0 32.0 14.0 8.0
{   81} > $GENERATE LOAD INITIAL 1000 PRINT OFF
{   82} > $
{   83} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 180.0 32.0 14.0 32.0 14.0 8.0
{   84} > $GENERATE LOAD INITIAL 2000 PRINT OFF
{   85} > $
{   86} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 185.0 32.0 14.0 32.0 14.0 8.0
{   87} > $GENERATE LOAD INITIAL 3000 PRINT OFF
{   88} > $
{   89} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 190.0 32.0 14.0 32.0 14.0 8.0
{   90} > $GENERATE LOAD INITIAL 4000 PRINT OFF
{   91} > $
{   92} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 195.0 32.0 14.0 32.0 14.0 8.0
{   93} > $GENERATE LOAD INITIAL 5000 PRINT OFF
{   94} > $
{   95} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 200.0 32.0 14.0 32.0 14.0 8.0
{   96} > $GENERATE LOAD INITIAL 6000 PRINT OFF
{   97} > $
{   98} > $TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 205.0 32.0 14.0 32.0 14.0 8.0
{   99} > $GENERATE LOAD INITIAL 7000 PRINT OFF
{  100} > $
{  101} > $END LOAD GENERATOR
{  102} >
{  103} > $ --- TRIAL 2 - (GOAL: Determine extreme values using refined headway spacing)
{  104} > $ --- Load ID Legend
```

```
{  105} > $ - ID = 1000 TO 1999,  50' Headway Spacing
{  106} > $ - ID = 2000 TO 2999, 193' Headway Spacing
{  107} > $ - ID = 3000 TO 3999, 194' Headway Spacing
{  108} > $ - ID = 4000 TO 4999, 195' Headway Spacing
{  109} > $ - ID = 5000 TO 5999, 196' Headway Spacing
{  110} > $ - ID = 6000 TO 6999, 197' Headway Spacing
{  111} > $ - ID = 7000 TO 7999, 198' Headway Spacing
{  112} >
{  113} > MOVING LOAD GENERATOR
{  114} >
{  115} > SUPERSTRUCTURE FOR MEMBERS 1 TO 3
{  116} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0  50.0 32.0 14.0 32.0 14.0 8.0
{  117} > GENERATE LOAD INITIAL 1000 PRINT OFF
{  118} >
{  119} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 193.0 32.0 14.0 32.0 14.0 8.0
{  120} > GENERATE LOAD INITIAL 2000 PRINT OFF
{  121} >
{  122} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 194.0 32.0 14.0 32.0 14.0 8.0
{  123} > GENERATE LOAD INITIAL 3000 PRINT OFF
{  124} >
{  125} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 195.0 32.0 14.0 32.0 14.0 8.0
{  126} > GENERATE LOAD INITIAL 4000 PRINT OFF
{  127} >
{  128} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 196.0 32.0 14.0 32.0 14.0 8.0
{  129} > GENERATE LOAD INITIAL 5000 PRINT OFF
{  130} >
{  131} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 197.0 32.0 14.0 32.0 14.0 8.0
{  132} > GENERATE LOAD INITIAL 6000 PRINT OFF
{  133} >
{  134} > TRUCK FWD GENERAL TRUCK 32.0 14.0 32.0 14.0 8.0 198.0 32.0 14.0 32.0 14.0 8.0
{  135} > GENERATE LOAD INITIAL 7000 PRINT OFF
{  136} >
{  137} > END LOAD GENERATOR
*** OUT OF MOVING LOAD GENERATOR
{  138} > $
{  139} > $ -------------- Analysis
{  140} > $
{  141} > STIFFNESS ANALYSIS
TIME FOR CONSISTENCY CHECKS FOR      5 MEMBERS      0.06 SECONDS
TIME FOR BANDWIDTH REDUCTION                        0.00 SECONDS
TIME TO GENERATE      5 ELEMENT STIF. MATRICES      0.05 SECONDS
TIME TO PROCESS     1337 MEMBER LOADS               0.05 SECONDS
TIME TO ASSEMBLE THE STIFFNESS MATRIX               0.02 SECONDS
TIME TO PROCESS      6 JOINTS                       0.01 SECONDS
TIME TO SOLVE WITH    1 PARTITIONS                  0.01 SECONDS
```

```
 TIME TO PROCESS      6 JOINT DISPLACEMENTS          0.02 SECONDS
 TIME TO PROCESS      5 ELEMENT DISTORTIONS          0.04 SECONDS
 TIME FOR STATICS CHECK                              0.01 SECONDS
 {  142} > $
 {  143} > $ ------------- Results
 {  144} > $
 {  145} > OUTPUT BY MEMBER
 {  146} >
 {  147} > $ ----------- Dual Truck Results Envelope (top and bottom of pier)
 {  148} > LOAD LIST 1000 TO 7999
 {  149} > LIST FORCE ENVELOPE MEMBER 4 SECTION FRACTIONAL NS 2 1.0 0.0
1

   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  4
-------------------------------------------------------------------------------------------------------------------------------

   DISTANCE         /-------------------  FORCE  -------------------//-----------------  MOMENT  -----------------/
  FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR           5.504462        21.75733                                                       459.4002
                           6047           1018                                                           3024
                       -117.8832       -17.13201                                                      -582.5873
                           1014           3024                                                           1018

    0.000               5.504462        21.75733                                                       287.7058
                           6047           1018                                                           1018
                       -117.8832       -17.13201                                                      -225.8802
                           1014           3024                                                           3024
```

```
{  150} >
{  151} > $ ----------- Lane Load Results Envelope (top and bottom of pier)
{  152} > LOAD LIST 'LS12' 'LS13' 'LS2' 'LS3'
{  153} > LIST FORCE ENVELOPE MEMBER 4 SECTION FRACTIONAL NS 2 1.0 0.0


   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  4
-------------------------------------------------------------------------------------------------------------------------------

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR           3.302270        13.59967                                                       276.7290
                           LS3            LS2                                                             LS13
                       -89.14960       -10.33223                                                      -364.2411
                           LS12           LS13                                                            LS2

    0.000               3.302270        13.59967                                                       179.7457
                           LS3            LS2                                                             LS2
                       -89.14960       -10.33223                                                      -136.5602
                           LS12           LS13                                                            LS13


{  154} >
{  155} > $ ----------- Corresponding force effects maximum axial, shear, and moment
{  156} > LOAD LIST 1014 1018 'LS12' 'LS2'
```

```
{  157} > LIST SECTION FORCES MEMBER 4 SECTION FRACTIONAL NS 2 1.0 0.0

   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER SECTION FORCES

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  4
-------------------------------------------------------------------------------------------------------------------------------


         LOADING    LS12        Load load in span 1 and 2

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR          -89.14960        8.433558                                                      -195.4770
    0.000              -89.14960        8.433558                                                       141.8653


         LOADING    LS2         Load load in span 2

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR          -49.40132        13.59967                                                      -364.2411
    0.000              -49.40132        13.59967                                                       179.7458


         LOADING    1014        USERS TRUCK      FORWARD  PIVOT ON SECTION  2    MEMBER 2

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
```

```
FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

  1.000  FR          -117.8832        6.239560                                                      -146.2155
  0.000              -117.8832        6.239560                                                       103.3669


       LOADING    1018        USERS TRUCK      FORWARD  PIVOT ON SECTION  6    MEMBER 2

 DISTANCE         /------------------  FORCE  ------------------//-----------------  MOMENT  -----------------/
FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

  1.000  FR          -85.84380        21.75733                                                      -582.5874
  0.000              -85.84380        21.75733                                                       287.7058
```

12. *Transverse Analysis Details*

The following output shows the details of the transverse analysis. The interesting thing to note about the transverse analysis is the live load truck configuration. A technique of treating the wheel line reactions as a longitudinal live load is used. A two axle “truck” is created. The truck is positioned so that it is on the left edge, center, and right edge of the design lane. In order to keep the axles in the correct position, a dummy axle with a weight of 0.0001 kips was used. This dummy axial is the lead axle of the truck and it is positioned in such a way as to cause the two “real” axles to fall in the correct locations within the design lanes.

The GTSTRUDL live load generator uses partial trucks when it is bring a truck onto or taking it off a bridge. As such, less then the full number of axles are applied to the model. For the transverse analysis, we do not want to consider the situation when only one of the two wheel lines is on the model. As such, several load cases are ignored by way of the LOAD LIST command on line76 of the output.

```
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# Wed Nov 19 09:23:01 2003


1GTICES/C-NP 2.5.0 MD-NT 2.0, January 1995.
 Proprietary to Georgia Tech Research Corporation, U.S.A.

Reading password file J:\GTSTRUDL\Gtaccess26.dat
 CI-i-audfile, Command AUDIT file FILE0923.aud has been activated.

 *** G T S T R U D L ***
    RELEASE DATE          VERSION             COMPLETION NO.
    February, 2002        26.0                    4290

 **** ACTIVE UNITS -  LENGTH   WEIGHT   ANGLE    TEMPERATURE   TIME
 **** ASSUMED TO BE     INCH    POUND   RADIAN    FAHRENHEIT   SECOND


 {    1} > $ ---------------------------------------------------------
 {    2} > $ This is the Common Startup Macro; put your company-wide startup commands
here.
 {    3} > $ You can edit this file from Tools -- Macros.  Click "Startup" and then
"Edit".
 {    4} > $ ---------------------------------------------------------
```

```
{    1} > CINPUT 'C:\Documents and Settings\bricer\My Documents\BDM\HL93 Live Load -
{    2} >_Analysis of Piers\Transverse.gti'
{    3} > $ -------------------------------------------------------
{    4} > $ Live Load Pier Analysis Example
{    5} > $ Transverse Anaysis to determine column loads
{    6} > $ -------------------------------------------------------
{    7} > $
{    8} > STRUDL
```

```
 ******************************************************************
 *                                                                *
 *   ******                          G T S T R U D L              *
 *  ********                                                      *
 *  **    **                                                      *
 *  **               *****  ******  *****   **  **  *****   **    *
 *  **  **********  ******  ******  ******  **  **  ******  **    *
 *  **  **********  **        **    **  **  **  **  **  **  **    *
 *  **    ****      *****     **    ******  **  **  **  **  **    *
 *  **********       *****    **    *****   **  **  **  **  **    *
 *   ****** **          **    **    ** **   **  **  **  **  **    *
 *          **      ******    **    **  **  ******  ******  *******
 *          **      *****     **    **  **   ****   *****   *******
 *          **                                                    *
 *          **                 OWNED BY AND PROPRIETARY TO THE    *
 *          **                 GEORGIA TECH RESEARCH CORPORATION  *
 *                                                                *
 *  RELEASE DATE         VERSION             COMPLETION NO.       *
 *  February, 2002       26.0                    4290             *
 *                                                                *
 ******************************************************************
```

```
**** ACTIVE UNITS -  LENGTH   WEIGHT   ANGLE    TEMPERATURE   TIME
**** ASSUMED TO BE     INCH    POUND   RADIAN    FAHRENHEIT   SECOND

{    9} > TYPE PLANE FRAME XY
{   10} > MATERIAL STEEL
{   11} > OUTPUT LONG NAME
{   12} > UNITS FEET KIPS
```

```
{   13} > $
{   14} > JOINT COORDINATES
{   15} > $      Name             X coord            Y coord
{   16} > $  --------       -------------       ------------
{   17} >           1           -14.00000           40.00000
{   18} >           2            -7.00000           40.00000
{   19} >           3             7.00000           40.00000
{   20} >           4            14.00000           40.00000
{   21} >           5            -7.00000            0.00000 S
{   22} >           6             7.00000            0.00000 S
{   23} > $
{   24} > $
{   25} > MEMBER INCIDENCES
{   26} > $      Name  Start joint  End joint
{   27} > $  --------     --------   --------
{   28} >           1            1          2
{   29} >           2            2          3
{   30} >           3            3          4
{   31} >           4            5          2
{   32} >           5            6          3
{   33} > $
{   34} > $ ------------- Properties ----------------
{   35} > UNITS INCHES
{   36} > MEMBER PROPERTIES
{   37} >    1 TO 3  AX 64935 IZ 6283008 $ CAP BEAM
{   38} >    4 TO 5  AX  2827 IZ  636172 $ COLUMNS
{   39} > UNITS FEET
{   40} > $
{   41} > $ ------------- Loadings ------------------
{   42} > $
{   43} > MOVING LOAD GENERATOR
{   44} > SUPERSTRUCTURE FOR MEMBERS 1 TO 3
{   45} >
{   46} > $ One lane loaded - Left Aligned
{   47} > TRUCK FWD GENERAL TRUCK NP 3 110.7 6 110.7 0.875 0.0001
{   48} > GENERATE LOAD INITIAL 1000 PRINT OFF
{   49} >
{   50} > $ One lane loaded - Center Aligned
{   51} > TRUCK FWD GENERAL TRUCK NP 3 110.7 6 110.7 2.125 0.00001
{   52} > GENERATE LOAD INITIAL 1300 PRINT OFF
{   53} >
{   54} > $ One lane loaded - Right Aligned
{   55} > TRUCK FWD GENERAL TRUCK NP 3 110.7 6 110.7 3.125 0.0001
{   56} > GENERATE LOAD INITIAL 1500 PRINT OFF
{   57} >
```

```
{   58} >
{   59} > $ Two lanes loaded - Left Aligned
{   60} > TRUCK FWD GENERAL TRUCK NP 5 110.7 6 110.7 6 110.7 6 110.7 0.875 0.0001
{   61} > GENERATE LOAD INITIAL 2000 PRINT OFF
{   62} >
{   63} > $ Two lanes loaded - Center Aligned
{   64} > TRUCK FWD GENERAL TRUCK NP 5 110.7 6 110.7 6 110.7 6 110.7 2.125 0.00001
{   65} > GENERATE LOAD INITIAL 2300 PRINT OFF
{   66} >
{   67} > $ Two lanes loaded - Right Aligned
{   68} > TRUCK FWD GENERAL TRUCK NP 5 110.7 6 110.7 6 110.7 6 110.7 3.125 0.0001
{   69} > GENERATE LOAD INITIAL 2500 PRINT OFF
{   70} >
{   71} > END LOAD GENERATOR
*** OUT OF MOVING LOAD GENERATOR
{   72} > $
{   73} > $ -------------- Analysis
{   74} > $
{   75} > $ --- Keep active only those loads where all of the "axles" are on the structure
{   76} > LOAD LIST 1009 TO 1029 1311 TO 1330 1513 TO 1531  2026 TO 2037 2328 TO 2338 2530 TO 2539
{   77} > STIFFNESS ANALYSIS
TIME FOR CONSISTENCY CHECKS FOR      5 MEMBERS      0.00 SECONDS
TIME FOR BANDWIDTH REDUCTION                        0.00 SECONDS
TIME TO GENERATE      5 ELEMENT STIF. MATRICES      0.00 SECONDS
TIME TO PROCESS      345 MEMBER LOADS               0.01 SECONDS
TIME TO ASSEMBLE THE STIFFNESS MATRIX               0.00 SECONDS
TIME TO PROCESS      6 JOINTS                       0.00 SECONDS
TIME TO SOLVE WITH    1 PARTITIONS                  0.00 SECONDS
TIME TO PROCESS      6 JOINT DISPLACEMENTS          0.01 SECONDS
TIME TO PROCESS      5 ELEMENT DISTORTIONS          0.00 SECONDS
TIME FOR STATICS CHECK                              0.00 SECONDS
{   78} > $
{   79} > $ ------------- Results
{   80} > $
{   81} > $ CAP BEAM RESULTS (FACE OF COLUMN AND CENTERLINE BEAM)
{   82} > LIST FORCE ENVELOPE MEMBER 1 SECTION NS 1 4.5
1

   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN
```

```
    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC

    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  1                                                                                                            -
-------------------------------------------------------------------------------------------------------------------------------

   DISTANCE         /-------------------  FORCE  -------------------//-----------------  MOMENT  ------------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    4.500             0.0000000E+00    110.7001                                                       0.4612272E-11
                          1009            1009                                                           2539
                      0.0000000E+00  -0.3200976E-11                                                   -401.2880
                          1010            2336                                                           1009


{   83} > LIST FORCE ENVELOPE MEMBER 2 SECTION NS 3 2.5 7 11.5


   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC

    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  2                                                                                                            -
-------------------------------------------------------------------------------------------------------------------------------
```

```
   DISTANCE         /-------------------  FORCE  -------------------//-----------------  MOMENT  -----------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    2.500              1.064582        55.64646                                                        314.3994
                          1029           1029                                                            1522
                    -0.7828730       -155.8126                                                        -522.0231
                          1021           2330                                                            1009

    7.000              1.064582        87.92229                                                        426.4992
                          1029           2036                                                            1520
                    -0.7828730       -87.92228                                                        -400.5730
                          1021           2328                                                            1029

   11.500              1.064582        155.8126                                                        301.1816
                          1029           2034                                                            1022
                    -0.7828730       -44.21778                                                        -650.9821
                          1021           1009                                                            1029


{   84} > LIST FORCE ENVELOPE MEMBER 3 SECTION NS 1 2.5


   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  3
-------------------------------------------------------------------------------------------------------------------------------

   DISTANCE         /-------------------  FORCE  -------------------//-----------------  MOMENT  -----------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING
```

```
   2.500              0.1944455E-10   0.1574852E-11                                                    0.7038116E-05
                          2037            1526                                                             2533
                      0.0000000E+00   -110.7000                                                        -484.3125
                          1010            1026                                                             1029


{   85} >
{   86} > $ COLUMN TOP AND BOTTOM RESULTS
{   87} > LIST FORCE ENVELOPE MEMBER 4 SECTION FRACTIONAL NS 2 1.0 0.0


   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER FORCE ENVELOPE

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  4
-------------------------------------------------------------------------------------------------------------------------------

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START              AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR           55.64646       0.7828730                                                       59.30810
                           1029            1021                                                             1009
                      -347.5455       -1.064582                                                       -27.00405
                           2026            1029                                                             2539

    0.000               55.64646       0.7828730                                                       28.35656
                           1029            1021                                                             2026
                      -347.5455       -1.064582                                                       -53.63107
                           2026            1029                                                             1029
```

```
{   88} >
{   89} > $ RESULTS CORRESPONDING TO MIN/MAX VALUES
{   90} > $ Corresponding values not needed for cross beam
{   91} > $ COLUMN TOP AND BOTTOM RESULTS
{   92} > LOAD LIST 1009 1029 2026 2539
{   93} > LIST SECTION FORCES MEMBER 4 SECTION FRACTIONAL NS 2 1.0 0.0


   ****************************
   *RESULTS OF LATEST ANALYSES*
   ****************************


    PROBLEM - NONE      TITLE - NONE GIVEN


    ACTIVE UNITS  FEET KIP  RAD  DEGF SEC


    INTERNAL MEMBER RESULTS
    -----------------------

     MEMBER SECTION FORCES

-------------------------------------------------------------------------------------------------------------------------------
---      MEMBER  4
-------------------------------------------------------------------------------------------------------------------------------


         LOADING    1009        USERS TRUCK      FORWARD  PIVOT ON SECTION  0    MEMBER 1

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR          -265.6179      -0.8585348                                                      59.30810
    0.000              -265.6179      -0.8585348                                                      24.96671


         LOADING    1029        USERS TRUCK      FORWARD  PIVOT ON SECTION  0    MEMBER 3

   DISTANCE         /-------------------  FORCE  -------------------//------------------  MOMENT  ------------------/
  FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

    1.000  FR           55.64647       -1.064582                                                      -11.04779
    0.000               55.64647       -1.064582                                                      -53.63107
```

```
      LOADING    2026        USERS TRUCK      FORWARD  PIVOT ON SECTION  0    MEMBER 1

 DISTANCE         /------------------  FORCE  ------------------//-----------------  MOMENT  -----------------/
FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

  1.000  FR          -347.5455      -0.1425789                                                       34.05972
  0.000              -347.5455      -0.1425789                                                       28.35657


      LOADING    2539        USERS TRUCK      FORWARD  PIVOT ON SECTION  9    MEMBER 1

 DISTANCE         /------------------  FORCE  ------------------//-----------------  MOMENT  -----------------/
FROM START               AXIAL         Y SHEAR         Z SHEAR         TORSION       Y BENDING       Z BENDING

  1.000  FR          -86.08118      -0.2046868                                                      -27.00405
  0.000              -86.08118      -0.2046868                                                      -35.19152
```