# Structural Load Rating Calculations

## Volume 7B
### Section 8.0 to 8.6

**CLINE AVENUE BRIDGE**
**S.R. 912 OVER THE INDIANA HARBOR CANAL**
**AT EAST CHICAGO, INDIANA**
**LAKE COUNTY**

**Prepared by:**

URS

**OCTOBER, 2009**

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| | 5.9.8 Load Summary Striped Locations | 3 | PT | IC by RJB |
| | 5.9.9 Operating Rating Evaluations Striped Lanes | 4 | PT | IC by RJB |
| | 5.9.10 Inventory Rating Evaluations Striped Lanes | 4 | PT | IC by RJB |
| Volume 7A | **6 Longitudinal Analysis Independent Check** | 1 | PT | IC |
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| | 6.1.1 Results Comparison | 9 | PT | IC |
| | 6.1.2 Tango Model | 1 | PT | IC |
| | 6.1.3 Tango Input | 20 | PT | IC |
| | 6.2 Segment 2 EB | | | |
| | 6.2.1 Results Comparison | 9 | PT | IC |
| | 6.2.2 Tango Model | 1 | PT | IC |
| | 6.2.3 Tango Input | 15 | PT | IC |
| | 6.3 Segment 2 WB | | | |
| | 6.3.1 Results Comparison | 9 | PT | IC |
| | 6.3.2 Tango Model | 1 | PT | IC |
| | 6.3.3 Tango Input | 16 | PT | IC |
| | 6.4 Segment 3 EB | | | |
| | 6.4.1 Results Comparison | 6 | PT | IC |
| | 6.4.2 Tango Model | 1 | PT | IC |

| | | Number of Pages | Designed | Checked |
|---|---|---|---|---|
| | 6.4.3 Tango Input | 21 | PT | IC |
| Volume 7A | 6.5 Segment 3 WB | | | |
| | 6.5.1 Results Comparison | 6 | PT | IC |
| | 6.5.2 Tango Model | 1 | PT | IC |
| | 6.5.3 Tango Input | 25 | PT | IC |
| | 6.6 Segment 4 EB | | | |
| | 6.6.1 Results Comparison | 9 | PT | IC |
| | 6.6.2 Tango Model | 1 | PT | IC |
| | 6.6.3 Tango Input | 17 | PT | IC |
| | 6.7 Segment 4 WB | | | |
| | 6.7.1 Results Comparison | 6 | PT | IC |
| | 6.7.2 Tango Model | 1 | PT | IC |
| | 6.7.3 Tango Input | 16 | PT | IC |
| | 6.8 Segment 5 EB | | | |
| | 6.8.1 Results Comparison | 6 | PT | IC |
| | 6.8.2 Tango Model | 1 | PT | IC |
| | 6.8.3 Tango Input | 19 | PT | IC |
| | 6.9 Segment 5 WB | | | |
| | 6.9.1 Results Comparison | 6 | PT | IC |
| | 6.9.2 Tango Model | 1 | PT | IC |
| | 6.9.3 Tango Input | 16 | PT | IC |
| | 6.10 Segment 6 EB | | | |
| | 6.10.1 Results Comparison | 6 | PT | IC |
| | 6.10.2 Tango Model | 1 | PT | IC |
| | 6.10.3 Tango Input | 15 | PT | IC |
| | 6.11 Segment 6 WB | | | |
| | 6.11.1 Results Comparison | 6 | PT | IC |
| | 6.11.2 Tango Model | 1 | PT | IC |
| | 6.11.3 Tango Input | 16 | PT | IC |
| | 6.12 Ramp A | | | |
| | 6.12.1 Results Comparison | 9 | PT | IC |
| | 6.12.2 Tango Model | 6 | PT | IC |
| | 6.12.3 Tango Input | 23 | PT | IC |
| | 6.13 Ramp B | | | |
| | 6.13.1 Results Comparison | 9 | PT | IC |
| | 6.13.2 Tango Model | 1 | PT | IC |
| | 6.13.3 Tango Input | 8 | PT | IC |
| | 6.14 Ramp C | | | |
| | 6.14.1 Results Comparison | 9 | PT | IC |
| | 6.14.2 Tango Model | 1 | PT | IC |
| | 6.14.3 Tango Input | 12 | PT | IC |
| | 6.15 Ramp D | | | |
| | 6.15.1 Results Comparison | 9 | PT | IC |
| | 6.15.2 Tango Model | 1 | PT | IC |
| | 6.15.3 Tango Input | 7 | PT | IC |
| | 6.16 Temperature Gradient Comparison | 10 | PT | IC |
| | 6.17 Permit Truck Live Load Comparison | 10 | PT | IC |
| | **7 Transverse Analysis Verification** | | | |
| | 7.1 Summary | 1 | PT | N/A |
| | 7.2 Minimum Live Load Moment at Edge of Cantilever | | | |
| | 7.2.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.2.2 Brug Results | 1 | PT | N/A |
| | 7.2.3 Homberg Chart Results | 3 | PT | N/A |
| | 7.2.3.1 Homberg Charts – Fixed End Moment Beam | 9 | PT | N/A |
| | 7.2.3.2 Homberg Charts – Continuous Beam | 3 | PT | N/A |
| | 7.3 Minimum Live Load Moment at Edge of Web | | | |
| | 7.3.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.3.2 Brug Results | 1 | PT | N/A |
| | 7.3.3. Homberg Chart Results | 2 | PT | N/A |

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Item: Calculation Index
File: V:\Projects\Cline Avenue\Calc Index\[Calculation_Index.xls]Index

| | | Number of Pages | Designed | Checked |
|---|---|---|---|---|
| | 7.3.3.1 Homberg Charts – Fixed End Moment Beam | 2 | PT | N/A |
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| Volume 7A | 7.4 Minimum Live Load Moment at Top Slab - Thickness Change Location | | | |
| | 7.4.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.4.2 Brug Results | 1 | PT | N/A |
| | 7.4.3 Homberg Chart Results | 4 | PT | N/A |
| | 7.4.3.1 Homberg Charts – Fixed End Moment Beam | 6 | PT | N/A |
| | 7.4.3.2 Homberg Charts – Continuous Beam | 6 | PT | N/A |
| | 7.5 Maximum Live Load Moment at Top Slab - Thickness Change Location | | | |
| | 7.5.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.5.2 Brug Results | 1 | PT | N/A |
| | 7.5.3 Homberg Chart Results | 4 | PT | N/A |
| | 7.5.3.1 Homberg Charts – Fixed End Moment Beam | 7 | PT | N/A |
| | 7.5.3.2 Homberg Charts – Continuous Beam | 6 | PT | N/A |
| | 7.6 Minimum Live Load Moment at Top Slab - Centerline | | | |
| | 7.6.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.6.2 Brug Results | 1 | PT | N/A |
| | 7.6.3 Homberg Chart Results | 3 | PT | N/A |
| | 7.6.3.1 Homberg Charts – Fixed End Moment Beam | - | PT | N/A |
| | 7.6.3.2 Homberg Charts – Continuous Beam | - | PT | N/A |
| | 7.7 Maximum Live Load Moment at Top Slab - Centerline | | | |
| | 7.7.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.7.2 Brug Results | 1 | PT | N/A |
| | 7.7.3 Homberg Chart Results | 2 | PT | N/A |
| | 7.7.3.1 Homberg Charts – Fixed End Moment Beam | 4 | PT | N/A |
| | 7.7.3.2 Homberg Charts – Continuous Beam | 3 | PT | N/A |
| | 7.8 Minimum Live Load Moment at Top of Web | | | |
| | 7.8.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.8.2 Brug Results | 1 | PT | N/A |
| | 7.8.3 Homberg Chart Results | 2 | PT | N/A |
| | 7.8.3.1 Homberg Charts – Fixed End Moment Beam | - | PT | N/A |
| | 7.8.3.2 Homberg Charts – Continuous Beam | - | PT | N/A |
| | 7.9 Maximum Live Load Moment at Top of Web | | | |
| | 7.9.1 Midas Results and Comparison | 1 | PT/DEM | N/A |
| | 7.9.2 Brug Results | 1 | PT | N/A |
| | 7.9.3 Homberg Chart Results | 2 | PT | N/A |
| | 7.9.3.1 Homberg Charts – Fixed End Moment Beam | - | PT | N/A |
| | 7.9.3.2 Homberg Charts – Continuous Beam | - | PT | N/A |
| | 7.10 2D GTSTRUDL Analysis – Equivalent Loads on Continuous Beam | 19 | PT | N/A |
| | 7.11 2D GTSTRUDL Analysis –Frame Model | 20 | PT | N/A |
| Volume 7E | **8 Review of Longitudinal Shear and Transverse Analysis** | | | |
| | 8.1 Summary | | RJB | N/A |
| | 8.2 References for Interaction of Longitudinal Shear and Transverse Bending | | RJB | N/A |
| | 8.3 Initial Review of Transverse Analysis | | RJB | N/A |
| | 8.4 Revised Transverse Analysis Based on Revised Effective Span Length | | RJB | N/A |
| | 8.5 Review of Longitudinal Shear Analysis (MATHCAD Analysis) | | RJB | N/A |
| | 8.6 Comparison of the MCFT Shear Analysis - Tabularized Values (2007) Vs. Equations (2009) | | RJB | N/A |
| Electronic Files | **8 Appendix A – GP Input Files - Geometry** | | DEM | |
| | **9 Appendix B - RM Input Files - Dead Load** | | DEM | |
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| | **10 Appendix D - Additional Longitudinal Rating Calculations** | | TSP | |
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**URS** **EXHIBIT 4.7-2**

## CALCULATION COVER SHEET

Client: Indiana DOT

Project Name: Cline Avenue LRFR Load Rating

Project/Calculation Number: Section 8.0

Title: Review of Longitudinal Shear and Transverse Analysis

Total Number of Pages (including cover sheet):

Total Number of Computer Runs:

Prepared by: Richard Beaupre Date: 10/1/2009

Checked by: Independent Check Date: 10/1/2009

Description and Purpose:
A Review of the Rating Analysis for Longitudinal Shear and Transverse Bending

Design Basis/References/Assumptions
Job Specific Criteria - See Section 1.2.

Remarks/Conclusions/Results:
See Section 8.1.

Calculation Approved by: 9 Nov 09
Project Manager/Date

Revision No.: Description of Revision: Approved by:
Project Manager/Date

# 8.0 Review of Longitudinal Shear and Transverse Analysis

## 8.1 Summary

## 8.1 Summary

| URS Corporation | Made by: RJB | Date: 2-Oct-09 | Job Number: |
|---|---|---|---|
| | Checked by: | Date: | Sheet Number: |
| For: Cline Ave. | Backchecked by: | Date: | |

A review of the rating analysis for longitudinal shear and transverse bending was completed for the webs.

These specific tasks were completed:

1. Review of original drawings to determine web widths and reinforcement.
2. Review of the May 2009 draft issue of the report.
3. Review of the Menn method for the interaction of transverse bending moment and shear.
4. Review of the latest BRUG analysis for the transverse bending analysis for both the AASHTO and striped lane cases. It was determined that the AASHTO lane cases had some inconsistencies since the computer runs were made with version 43 of the program which was found to have an error. The AASHTO cases were then run with version 44. Based upon the review, it was determined that the

effective length value given in line 1003 had an effect upon transverse bending moments. The length of span provided on the same line is for information only (not used). It was also determined that the boundary conditions provided in BRUG are basically a hinge at one end and a roller at the other end. Therefore, the effective length should be the distance between points of contraflexure. For the end spans, the effective length was assumed to be 0.75 L. For the interior spans, the effective length was assumed to 0.58 L. This effective length influences the global effects of the truck loadings. Initially, 250 foot effective length was utilized for all computer runs which were too conservative leading to higher transverse moments in the webs.

It was observed that for Section IVA that the wheel spacings were less than 4 feet when a legal/permit vehicle and HL93 were combined. Some conservatism in transverse moments can be attributed to this.

Also, all transverse analysis was done with 14" webs. It was discovered later on that some of the webs are 15" thick. It was decided not to rerun since the thicker webs extra capacity is nearly equivalent to the extra demand on the stiffer web.

5. A detailed check of the procedure to calculate the rating factor for longitudinal/shear and transverse web bending was completed. A detailed check of the MATHCAD sheet that was produced for the independent check of the rating factors (produced by EXCEL spreadsheets) for longitudinal shear/torsion and transverse bending moment was completed. Based upon this review, it was determined that the width of the web utilized for the rating factors needs to adjusted to take into account the duct width per 2009 AASHTO LRFD section 5.8.2.9 in determining the shear capacity of the web. This reduction was determined to be approximately 1.75" based on two 3.5" grouted ducts side to side.

6. A review of the method for determining $V_c$ based upon 2008 LRFD Section 5.8.3.4.2 which uses equations instead of tables per the method in the 2007 LRFD. The 2008 LRFD method is based upon Canadian Design Code (A23.2-M04, 2004). This method allows a higher $\beta$ factor which increases $V_c$. This method was verified per NCHRP Web-Only Document 78 and the NCHRP Report 549.
7. A review of the chart of the rating factors for Ramp D Segment 6 which was showing a severe spike near node 98. This appears to be based upon the zeroing out of the PT which was done for the longitudinal flexural rating factor. Severe spikes can be averaged over a panel length of the truss model.

# 8.2 References for Interaction of Longitudinal Shear and Transverse Bending

## 8.2 References for Interaction of Longitudinal Shear and Transverse Bending

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any structural function. The multiple-key (or castellated-joint) design embodies this concept and provides for simplicity, safety, and cost savings. Webs and flanges of the box section are provided with a large number of small interlocking keys designed to carry all stresses across the joint with no structural assistance from the resin. Figure 4.66 shows the comparison between the structural behavior of an early joint with a single web key and a joint with multiple keys, assuming that the epoxy resin has improperly set and hardened. It is now recommended that multiple keys be used in all precast segmental projects, as shown in Figure 4.67. With the current dimensions used for depth and height of multiple keys, the overall capacity of the joint is far in excess of the required minimum to transfer diagonal stresses safely up to the ultimate load state.

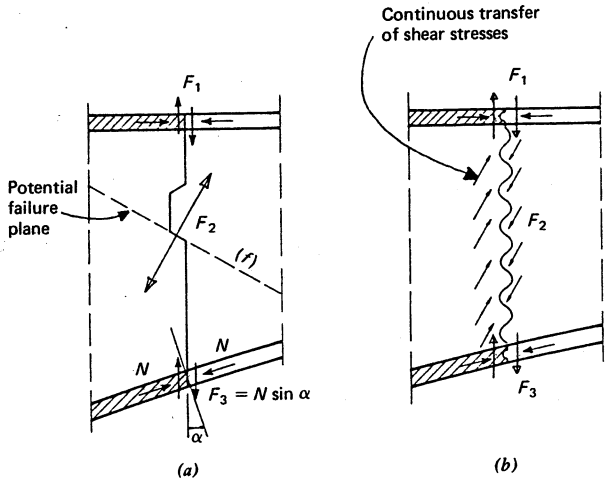


**FIGURE 4.66.** Joint between match-cast segments, comparison between single- and multiple-key concepts.

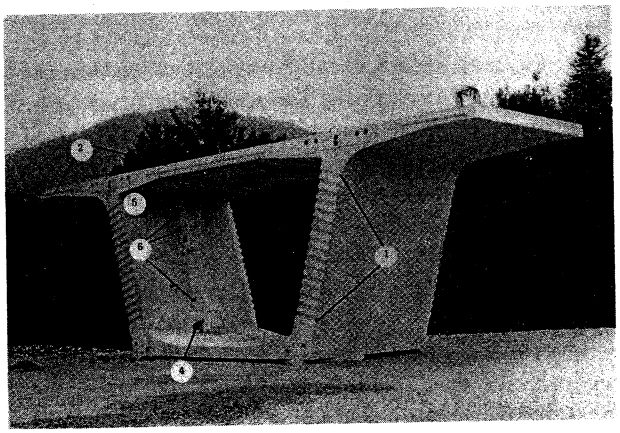

**FIGURE 4.67.** Precast segment with multiple keys.

## 4.12 Design of Superstructure Cross Section

The typical cross section of a box girder deck is a closed frame subjected to the following loads, Figure 4.68:

Girder weight of the various components (top and bottom flanges, webs)

Superimposed loads essentially applied to the top flange (barrier, curbs and pavement) and sometimes to the bottom flange, as when utilities are installed in the box girder

Live loads applied on the deck slab

A typical box girder element limited by two parallel cross sections, Figure 4.68*b*, is in equilibrium because the applied loads are balanced by the difference between shear stresses at the two limiting sections. To design the typical cross section the assumption is usually made that the shape of the section remains unchanged and that the closed frame may be designed as resting on immovable supports such as A and B. Bending moments are created in the various sections of the frame due to the applied loads. Maximum moments occur in the deck slab due to live loads in sections such as (a), (b), and (f).

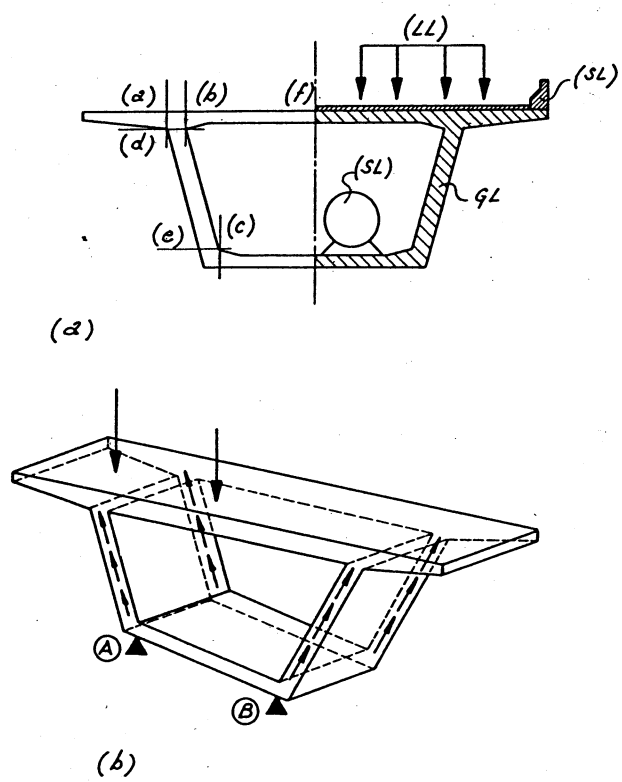


**FIGURE 4.68.** Design of deck cross section. (*a*) Typical loading on cross section. (*b*) Free-body diagram.

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Because the webs are usually much stiffer than the flanges and the side-deck slab cantilevers and the center-deck slab between webs are built into the webs, most of the deck-slab moments are transferred to the web, with a maximum value in section (d) at the connection between web and top flange. In bridges where transverse or vertical prestress or both are used, the design of the deck cross section is not greatly affected by the fact that moments and normal forces computed in the frame superimpose their effects on the shear stresses due to longitudinal bending mentioned in Section 4.10.

The case is more critical when only conventional transverse reinforcing steel is used in both flanges and webs. A common method, based on experience, is to compute the steel area required on either face at critical sections such as (a) through (e), shown in Figure 4.68, for the following:

1. Shear stresses in the longitudinal members.
2. Transverse bending of the frame.

The minimum amount of steel should not be less than the larger of the following:

item 1 plus one-half of item 2,

item 2 plus one-half of item 1, or

0.7 times the sum of item 1 and item 2.

## 4.13 *Special Problems in Superstructure Design*

All design aspects covered in the preceding sections pertain to the design of deck members for bending and shear regardless of the local problems encountered over the piers or abutments and at intermediate expansion joints when required. This section will now deal with such local problems, which are of great practical importance.

### 4.13.1 *DIAPHRAGMS*

It was mentioned in Section 4.6 that the combined capacities of the deck slab in bending and the box girder in torsion allow a very satisfactory transverse distribution of live loads between girders in the case of multiple box girder decks. It has therefore been common practice to eliminate all transverse diaphragms between box girders except over the abutments. Diaphragms inside the box section are still required over the intermediate piers in most projects.

### 4.13.2 *SUPERSTRUCTURE OVER PIERS*

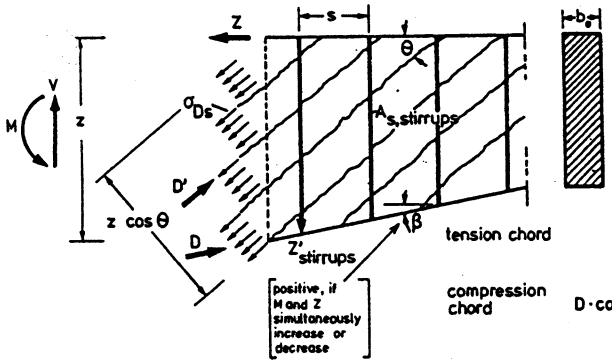
The simplest case is exemplified in Figure 4.69, where a deck of constant depth rests upon the pier cap with bearings located under the web of the box girder. The reaction is transferred directly from the web to the bearings, and there is need only for a simple inside diaphragm designed to transfer the shear stresses, due to possible torsion moments, to the substructure. A more complicated situation arises when the bearings are offset with regard to the webs, Figure 4.70. Reinforcing and possibly prestressing must be provided in the cross section immediately above the pier to fullfill the following functions:

Suspend all shear stresses carried by the web under point $A$, where a 45° line starting at the bearing edge intersects the web centerline (hatched area in the shear diagram).

Balance the moment ($R \cdot d$) induced by the bearing offset.

Looking at other schemes, we find that decks of variable depth pose several challenging problems. Figure 4.71 shows an elevation of a box girder resting on twin bearings designed to improve the rigidity of the pier-to-deck connection and consequently reduce the bending moments in the deck, which will be described in greater detail in Chapter 5.

When the loading arrangement is symmetrical in the two adjacent spans, the transfer of the deck reaction into the piers through the four bearings is just as simple as for the case shown in Figure 4.69. Matters look very difficult for an unsymmetrical loading condition either in the completed structure, Figure 4.71, or during construction, Figure 4.72. Let us assume that the total deck reaction is transferred to the pier through one line of bearings only (for example, $R_1$ in Figure 4.71, for an excess of load in the left span). The compression $C_2$ carried by the bottom flange at the right is no longer balanced by the corresponding reaction $R_2$, and an abrupt change in the system of internal forces results in a large vertical tensile force $T_2$, which has to be suspended on the total width of the box section by special reinforcement or prestress. In long-span structures, these local effects are of no small magnitude. Taking the example of a 40 ft (12 m) wide box with a 20 ft (6 m) wide bottom flange and a span of 300 ft (90 m), the load carried by the bottom flange will probably be around 3000 t (2720 mt) and the angle change above the right bearing




tension chord $Z = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[\frac{M}{z}(1-\cot\theta\cdot\tan\beta)+\frac{1}{2}V\cdot\cot\theta\right]$

compression chord $D\cdot\cos\beta = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[\frac{M}{z}+\frac{1}{2}V\cdot\cot\theta\right]$

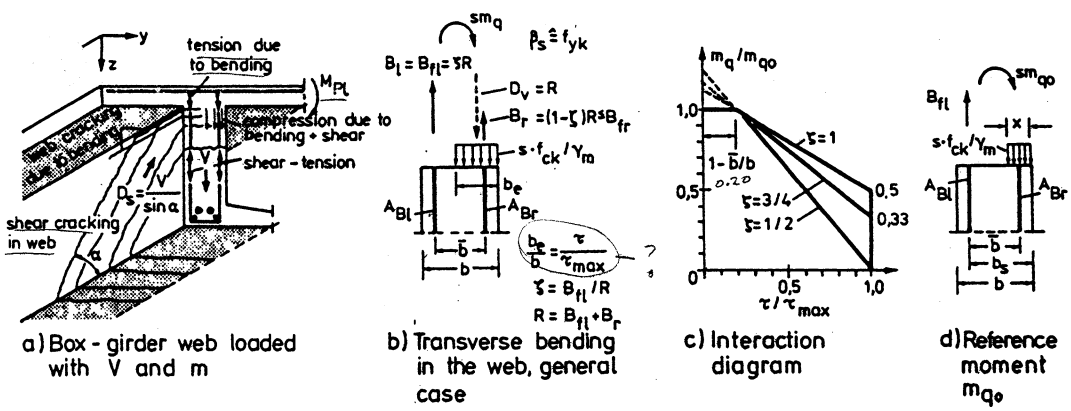
$V_{eff} = D'\cdot\sin\theta = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[V-\frac{M}{z}\tan\beta\right]$

stirrups $Z'_{stirrups} = D'\cdot\frac{s}{z}\sin\theta\ \tan\theta$

Fig. 26 Forces for the case of an inclined compression chord (from [22])

The design of the web for transverse bending has up until now normally been carried out separately for shear and for torsion, and the reinforcement for each has been fully superimposed. However, by projecting the compression members out of the plane of the truss, the truss can take a certain amount of transverse bending without additional reinforcement. This, however, leads to high concrete compression stresses in the contained compression member at web begin.

$\zeta = 0.5$ ($\tau_{yr.}$)




a) Box - girder web loaded with V and m

b) Transverse bending in the web, general case

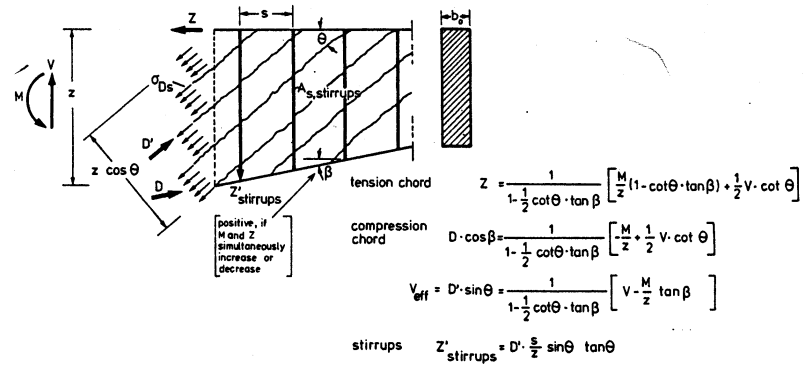
c) Interaction diagram

d) Reference moment $m_{qo}$

Fig. 27 Design for shear V and transverse bending m (from [23])

In [23] an interaction diagram with simplified assumptions is introduced (Figs. 27b and c) that allows a design for combined m and τ . For the given shear stress τ and $\zeta = 0.5$, ($B_{fl} = B_{fr}$), the largest transverse bending moment that can be handled without additional reinforcement is given below. This equation is also valid for $\zeta > 0.5$ (the selected reinforcement distribution, where $\zeta = B_{fl}/R$ and R = total force taken by the stirrups = $B_{fl} + B_{fr} = Z'_{stirrups}$).

$$m_q = \frac{R\cdot b}{2s}\cdot\left[1-\tau/\tau_{max} + \underbrace{(2\zeta-1)\cdot\bar{b}/b}_{0 \text{ if } B_{fl} = B_{fr}}\right]$$




$$Z = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[\frac{M}{z}(1-\cot\theta\cdot\tan\beta)+\frac{1}{2}V\cdot\cot\theta\right]$$

$$D\cdot\cos\beta = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[-\frac{M}{z}+\frac{1}{2}V\cdot\cot\theta\right]$$

$$V_{eff} = D'\cdot\sin\theta = \frac{1}{1-\frac{1}{2}\cot\theta\cdot\tan\beta}\left[V-\frac{M}{z}\tan\beta\right]$$

$$Z'_{stirrups} = D'\cdot\frac{s}{z}\sin\theta\ \tan\theta$$

Fig. 26 Forces for the case of an inclined compression chord (from [22])

The design of the web for transverse bending has up until now normally been carried out separately for shear and for torsion, and the reinforcement for each has been fully superimposed. However, by projecting the compression members out of the plane of the truss, the truss can take a certain amount of transverse bending without additional reinforcement. This, however, leads to high concrete compression stresses in the contained compression member at web begin.

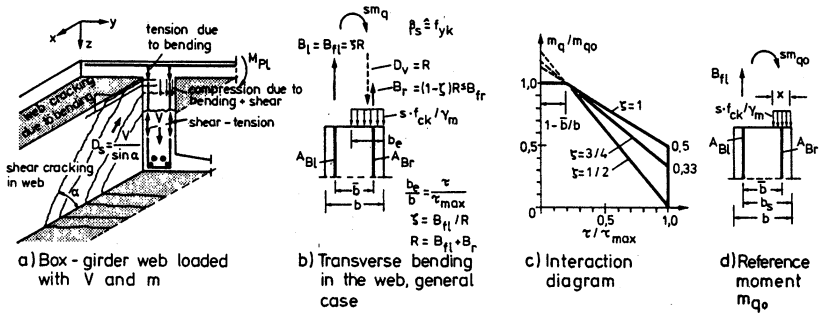



Fig. 27 Design for shear V and transverse bending m (from [23])

In [23] an interaction diagram with simplified assumptions is introduced (Figs. 27b and c) that allows a design for combined m and τ. For the given shear stress τ and $\zeta = 0.5$, ($B_{fl} = B_{fr}$), the largest transverse bending moment that can be handled without additional reinforcement is given below. This equation is also valid for $\zeta > 0.5$ (the selected reinforcement distribution, where $\zeta = B_{fl}/R$ and R = total force taken by the stirrups = $B_{fl} + B_{fr} = Z'_{stirrups}$).

$$m_q = \frac{R\cdot b}{2s}\cdot[1-\tau/\tau_{max}+(2\zeta-1)\cdot\bar{b}/b]$$

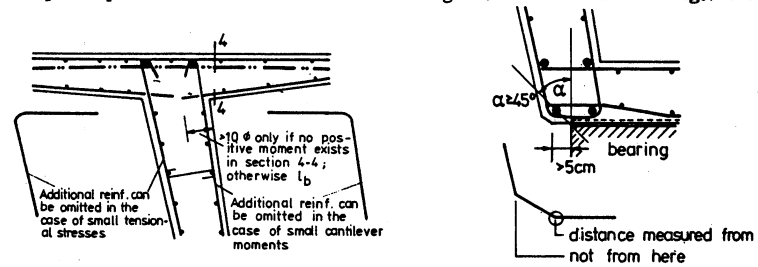


If for large transverse bending moments ($\zeta \to 1$) the actual moment $m_q$ is greater than $m_{qo} = \bar{b}\zeta R/s$, the web width must be increased.

Failure in compression is excluded if $A_{Bl}\cdot f_{yk} < s\cdot(b-\bar{b})\cdot f_{ck}/\gamma_m$.

## 5.2 Web Reinforcement

The principal reinforcement is shown in Fig. 7. For details see Fig. 28 be




a) Upper region of the web (see also Fig. 7, Detail c)

b) Position of bearir and reinforcemen the lower region the web

Fig. 28 Web reinforcement details

In order to avoid spalling at the support, the bottom flange should be desig as shown in Fig. 28 b.

The stirrups are mostly vertical. Only for extremely large shear or torsi are they inclined, or the webs are prestressed (Fig. 9).

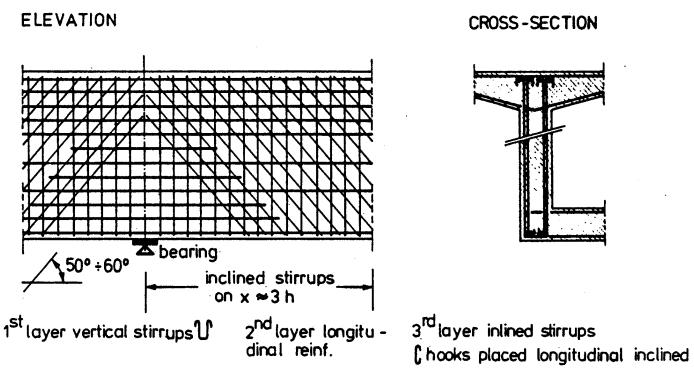



Fig. 29 Special case of inclined stirrups and vertical reinforcement for large shear (from [10])

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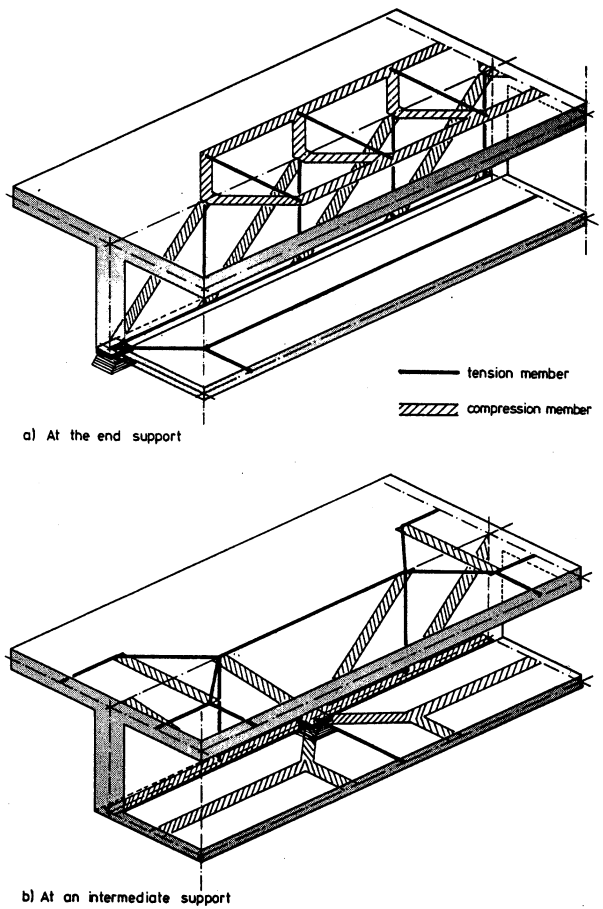
ereby creating compression stresses in the transverse direction [20]. Even one does not exploit the arching effect, the cantilevered portions should be ovided with robust edge reinforcement at their ends (Fig. 7, Detail a).

ıe connection of the top or bottom flange with the web should be determined ɔm equilibrium conditions by means of a complete strut model which includes e webs as well (Fig. 24).

ith the transverse bending moments, m, normally occurring in the flange multaneously, its design can be based upon Section 5.1, Fig. 27.



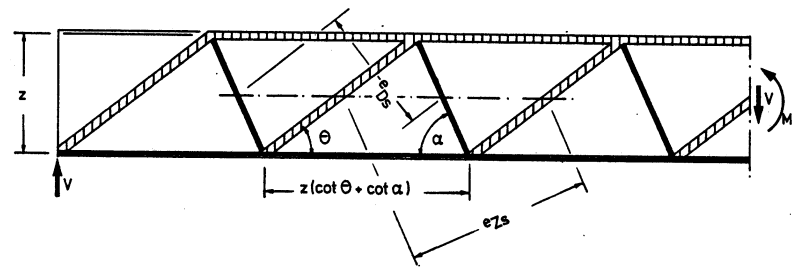

g. 24 Flow of forces (strut model near the support of a box-girder bridge; from [21] [14])



## 5. DIMENSIONING AND REINFORCEMENT OF THE WEBS

### 5.1 Dimensioning for Shear, Torsion and Transverse Bending

The webs of a box girder must not only handle shear but also torsion and tran verse bending. According to [1], the "refined method" should be used to ca culate the tension and compression strut forces occurring in the webs due to combined shear and torsion. The inclinations $\Theta$ (between 30° and 60°) of the web compression struts of the truss with parallel chords and the inclinations ( (90° in most cases), of the web tension ties, i.e. the stirrups, are thereby se ted and their forces determined (Fig. 25). In checking the web compression stresses, the cross-sectional reduction of the webs by the prestressing ducts should be considered, especially for slender webs (see Section 3.3.1).




| | | | |
|---|---|---|---|
| base lengths for the forces in the webs for a simple truss | $e_{zs} = z \cdot \sin\alpha(\cot\Theta + \cot\alpha)$<br>$e_{Ds} = z \cdot \sin\Theta(\cot\Theta + \cot\alpha)$ | percentage of shear reinf. in the web $\mu_s$<br>$e_{stirrups}$ $A_{s,stirrups}$ | $\mu_s = \frac{A_{s,stirrups}}{b_0 \cdot e_{stirrups} \cdot \sin\alpha}$ |
| compression chord<br>tension chord | $D = \frac{M}{z} - \frac{V}{2}(\cot\Theta - \cot\alpha)$<br>$Z = \frac{M}{z} + \frac{V}{2}(\cot\Theta - \cot\alpha)$ | compression forces in the web | $D'_s = \frac{V}{z} \cdot \frac{1}{\sin^2\Theta(\cot\Theta + \cot\alpha)}$<br>$\sigma_{Ds} = \frac{D'_s}{b_0}$ |
| tension forces in the webs | $Z'_{stirrups} = \frac{V}{z} \cdot \frac{1}{\sin^2\alpha(\cot\Theta + \cot\alpha)}$<br>$A_{s,stirrups} = \frac{Z'_{stirrups}}{\sigma_{s,stirrups}} e_{stirrups} \cdot \sin\alpha$ | "degree of shear coverage"<br>$\eta = \frac{Z'_s}{Z'_{s\,Mörsch}}$ | $\eta = \frac{1 + \cot\alpha}{\cot\Theta + \cot\alpha}$ |

Fig. 25 Definitions and forces in a parallel chord truss for bending and shea

In the case of a simultaneous combination with a torsional moment, $M_T$, the equations of Fig. 25 should contain instead of V the value $V^* = V + T$, with $T = M_T\, z / (2\, A_K)$.

If, as in the case of bridges constructed with the cantilever method, the compression chord is inclined, smaller tensile forces are produced for the determination of the stirrups; but larger forces occur in the tension chord (Fig. 26 Up until now the stirrups were designed for $V_{eff} = V - M/z \cdot \tan\beta$ and the larger tensile force in the chord was not considered, as it was safely covered by the usual staggering rules. To be consistent, however, the tension chord forces of Fig. 26 should be considered.

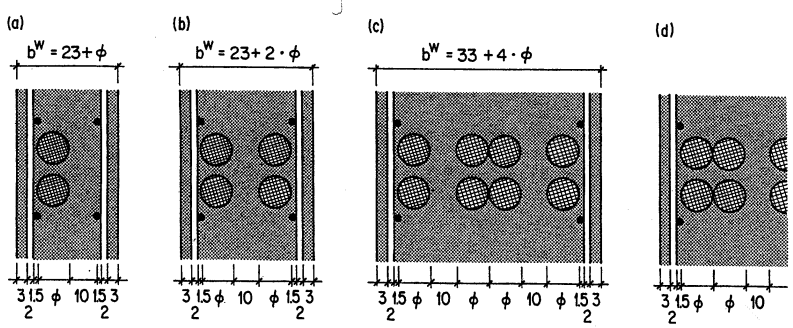



**Figure 5.55**
Minimum web width $b^w$ (dimensions in cm, $\phi =$ tendon duct diameter): a, b, c, tendon arrangements that permit proper placement and vibration of concrete; d, arrangement to be avoided

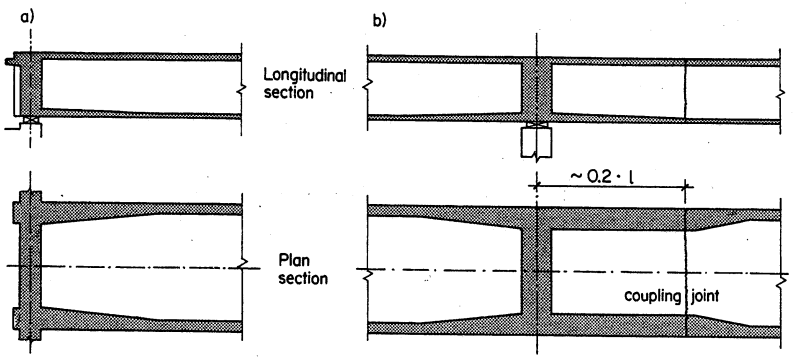



**Figure 5.56**
Increase in web width near supports: a, end supports; b, intermediate supports ($l =$ girder span length)

placement and vibration of concrete (fig. 5.55). Local web thickening is often required to accommodate tendon anchors or couplers near abutments and supports (fig. 5.56).

In normal cases, web thickness is fully utilized for shear resistance only in the immediate vicinity of the supports. The minimum required web thickness $b^w_{req}$ is obtained by setting the shear resistance of the stirrups $V_{R,s}$ equal to the shear resistance of the concrete $V_{R,c}$. (It is assumed that the given web reinforcement is fully utilized at the critical section):

$$V_{R,s} = \frac{A^w_s f_{sy}}{s} z(\cot\alpha + \cot\beta)\sin\beta \qquad \text{(equation (4.3))}$$



$$V_{R,c} = f_{c,red}\, b^w_{req}\, z(\cos\alpha + \cot\beta \sin\alpha)\sin\alpha \qquad \text{(equation (4.5))}$$

$$b^w_{req} = \gamma_R \gamma_S \frac{A^w_s f_{sy}}{s} \frac{\sin\beta}{f_{c,red}\sin^2\alpha} \qquad \text{(a)}$$

The notation of Section 4.3.3 is used throughout.

For constant $V_{R,s}$, an increase in the angle of inclination of the stirrups $\beta$ will result in a decrease in required web thickness. Equations (4.3), (a) and (4.4) are used to formulate the following expression:

$$b^w_{req}(\beta) = b^w_{req}(90°)\frac{\cot\alpha}{(\cot\alpha + \cot\beta)\sin\beta}$$

which gives the required web thickness for arbitrary stirrup inclination, $b^w_{req}(\beta)$, as a function of the width required when vertical stirrups are used, $b^w_{req}(90°)$. When $\alpha = \beta = 45°$, the relation simplifies to

$$b^w_{req}(45°) = \frac{1}{\sqrt{2}} b^w_{req}(90°)$$

which implies a 30 percent reduction in web width.

### *b) Web Design for Shear and Transverse Bending*

Webs must be designed to resist both longitudinal shear forces, $V$, and transverse bending moments, $m$. Simply summing the reinforcement required to resist each effect alone is not consistent with the actual behaviour of the web at ultimate limit state. The web reinforcement should rather be designed directly based on the combined effects of shear and transverse bending.

The minimum web width required to resist the factored shear force $\gamma_S V$ is obtained from equation (4.5):

$$b^w_{req} = \frac{\gamma_R \gamma_S V}{f_{c,red}\, z(\cos\alpha + \cot\beta \sin\alpha)\sin\alpha}$$

If $b^w_{req}$ is less than the actual web width $b^w$, the excess capacity can be used to resist transverse bending. When the web is in a state of pure shear, the resultant concrete compressive force $V/z\cot\alpha$ is located at the web centreline. In the presence of transverse bending, this force shifts towards the flexural compression side of the web (Kaufmann and Menn 1976). In the context of the truss model used for longitudinal shear design, this phenomenon can be regarded as an inclination of the compression diagonal out of the plane of the web axis to maintain equilibrium.

The effect of shifting the resultant compressive force is illustrated schematically in figure 5.57. Figure 5.57a shows the equilibrium of a web segment in pure shear. When the compressive force is shifted to the left, equilibrium is maintained by

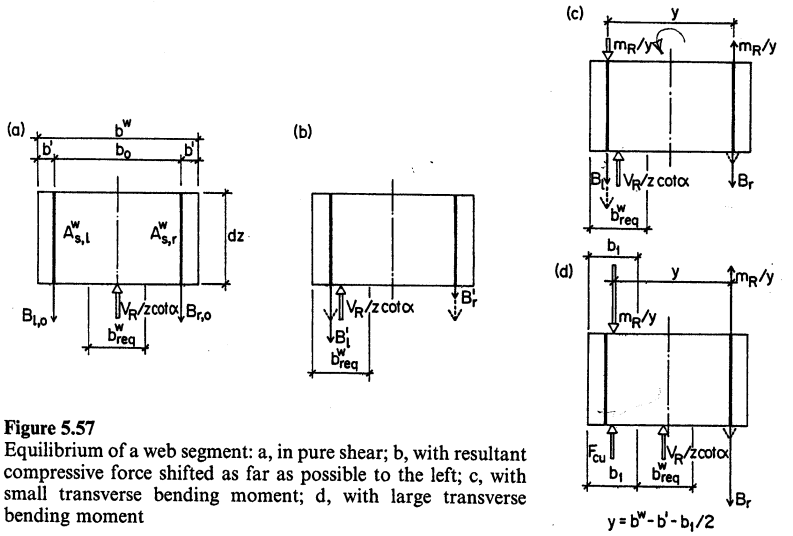



**Figure 5.57**
Equilibrium of a web segment: a, in pure shear; b, with resultant compressive force shifted as far as possible to the left; c, with small transverse bending moment; d, with large transverse bending moment

changes in the stirrup forces (fig. 5.57 b). The superimposed moment $m$ can then be resisted by further changes in the stirrup tensions (fig. 5.57 c) or, when the flexural compressive force $m/y$ is greater than $B'_l$, by an increase in the total concrete compressive force (fig. 5.57 d). A simple superposition of the stresses due to shear and the stresses due to transverse bending, without considering the shifting of the resultant compressive force, would result in a different state of equilibrium.

Based on these considerations, a simplified model for the ultimate resistance ($V_R$, $m_R$) of web sections subjected to shear and transverse bending can be formulated. It is assumed that the inclination angle of the compression struts, $\alpha$, and the internal lever arm, $z$, have been given (fig. 5.58) and that the stirrups are vertical ($\beta = 90°$). Concrete tensile strength is neglected and the concrete compressive stress distribution is modeled as a uniform stress block. Expressions for the stirrup forces $B_l$ and $B_r$ required to equilibrate ($V_R$, $m_R$) are derived here for the two cases shown in figures 5.57 c and 5.57 d:

1. Shear predominates (fig. 5.57 c):
   The resultant compressive force $V_R/z\cot\alpha$ is shifted as far as possible to the left. A net tensile force $B_l$ remains in the left stirrup after the displacement of $V_R/z\cot\alpha$ and the addition of the force couple due to $m$. Equilibrium is achieved without additional concrete compressive forces. The equilibrium equations

$$\frac{V_R}{z\cot\alpha} - B_l - B_r = 0$$

$$B_r b_0 - \frac{V_R}{z\cot\alpha}\left(\frac{b^w_{req}}{2} - b'\right) - m_R = 0$$



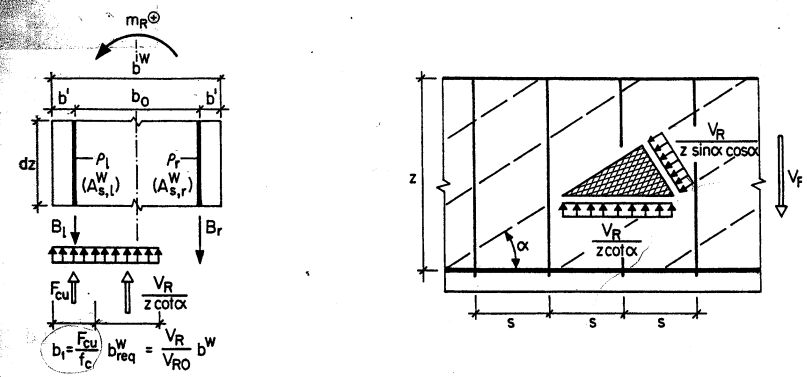



**Figure 5.58**
Symbols and sign convention

are solved to obtain the stirrup forces:

$$B_l = \frac{V_R}{z b_0 \cot\alpha}\left(b_0 - \frac{b^w_{req}}{2} + b'\right) - \frac{m_R}{b_0}$$

$$B_r = \frac{V_R}{z b_0 \cot\alpha}\left(\frac{b^w_{req}}{2} - b'\right) + \frac{m_R}{b_0}$$

2. Transverse bending predominates (fig. 5.57 d):
   In this case, the tensile force $B_l$ vanishes, and the additional concrete compressive force $F_{cu}$, equal to the product of the design compressive strength $f_c$ and the unknown width $b_1$, must be introduced to maintain equilibrium. The concrete compression due to shear must be shifted back towards the centreline of the web. The equilibrium equations are as follows:

$$\frac{V_R}{z\cot\alpha} + F_{cu} - B_r = 0$$

$$\frac{V_R}{z\cot\alpha}\left(\frac{b^w_{req} + b_1}{2}\right) + m_R - B_r\left(b^w - b' - \frac{b_1}{2}\right) = 0$$

The unknown stirrup force $B_r$ is given by

$$B_r = \frac{m_R + \frac{V_R}{z\cot\alpha}\left(\frac{b^w_{req} + b_1}{2}\right)}{b^W - b' - \frac{b_1}{2}}$$

In both cases, the web reinforcement must be sufficient to resist $B_r$ and, where applicable, $B_l$. The familiar equations are used: $A^w_{s,r} = sB_r/f_{sy}$ and $A^w_{s,l} = sB_l/f_{sy}$, where $s$ denotes stirrup spacing.

Given web reinforcement $A^w_{s,r}$ and $A^w_{s,l}$, the transverse bending resistance $m_R$ can be calculated as a function of shear resistance $V_R$ using the relationships derived above. Alternatively, $V_R$ can be calculated as a function of $m_R$. It is convenient to represent the relationships among $A^w_{s,r}$, $A^w_{s,l}$, $V_R$, and $m_R$ graphically in the form of an interaction diagram.

The symbols and sign conventions shown in figure 5.58 are used in the generation of the diagrams. Shear resistance $V_R$ is expressed as a dimensionless ratio $V_R/V_{R0}$, where $V_{R0}$ is the maximum resistance of the concrete in pure shear:

$$V_{R0} = f_{c,\mathrm{red}}\, b^w z \cos\alpha \sin\alpha \qquad (\text{See Eq. 4.5}).\quad V_{R0} = f_c\, b\, z \left(\tfrac{1}{2}\right)$$

Web reinforcement is described by the geometrical reinforcement ratios $\varrho$, $\varrho_l$, and $\varrho_r$, all of which are defined relative to the full web width:

$$\varrho = \frac{A^w_s}{b^w s}, \qquad \varrho_l = \frac{A^w_{s,l}}{b^w s}, \qquad \varrho_r = \frac{A^w_{s,r}}{b^w s}$$

where $A^w_s = A^w_{s,l} + A^w_{s,r}$. The ratio $\varrho$ is expressed as a percentage of the ratio $\varrho_0$, defined by the following equation:

$$\varrho_0 = \frac{f_{c,\mathrm{red}}}{f_{sy}} \sin^2\alpha \qquad = \frac{0.67(5)}{60}\left(\sin^2 45\right) = 0.02792 \quad \text{(b)}$$

The parameter $\varrho_0$ corresponds to the total web reinforcement $A^w_s$ such that $V_{R,s}$ is equal to $V_{R0}$. Equation (b) is obtained by substituting $b^w$ for $b^w_{\mathrm{req}}$ in equation (a), assuming $\beta = 90°$.

Transverse bending resistance is expressed as the dimensionless ratio $m_R/m_{R0}$, where $m_{R0}$ is the pure flexural resistance of the web with reinforcement ratio $\varrho_0$, assuming the stirrups are arranged symmetrically about the web centreline:

$$m_{R0} = \omega_0 (b_0 + b')^2 f_c \left(1 - \frac{\omega_0}{2}\right)$$

The ratio $\omega_0$ is the mechanical reinforcement ratio relative to the statical depth $b_0 + b'$ of the section:

$$\omega_0 = \frac{\varrho_0}{2}\,\frac{b^w}{b_0 + b'}\,\frac{f_{sy}}{f_c} = \frac{f_{c,\mathrm{red}} \sin^2\alpha}{2 f_c}\,\frac{b^w}{b_0 + b'}$$

Interaction diagrams have been generated for the typical case defined by $f_{c,\mathrm{red}}/f_c = 0.67$, $b'/b^w = 0.1$, and $\alpha = 45°$. They are given in figures 5.59 through 5.61 for $\varrho_r/\varrho_l = 1.0$, 1.5, and 2.0, respectively.

The design procedure consists first of calculating the reinforcement ratios $\varrho_0$ and $\omega_0$ based on the chosen web width ($b^w$), reinforcement location ($b'$), the given



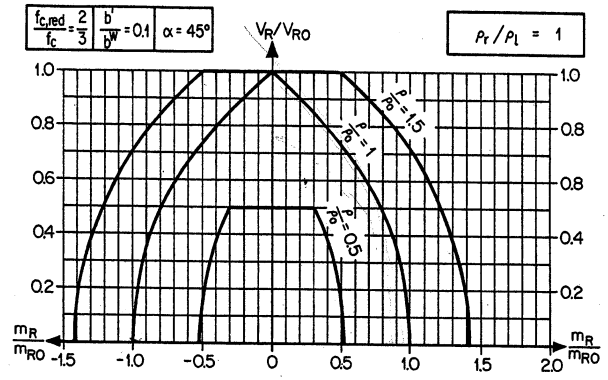



**Figure 5.59**
Shear-transverse bending interaction diagram for $\varrho_r/\varrho_l = 1.0$

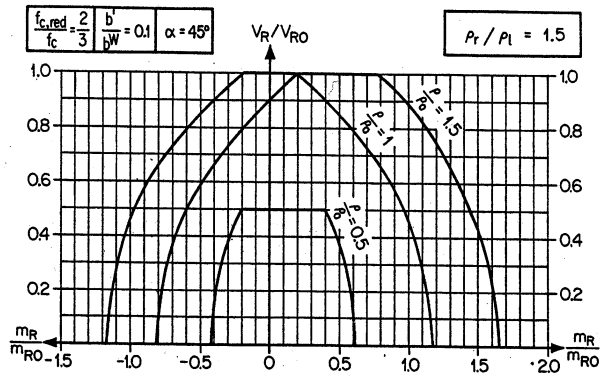



**Figure 5.60**
Shear-transverse bending interaction diagram for $\varrho_r/\varrho_l = 1.5$

material strengths ($f_c$, $f_{c,\mathrm{red}}$, and $f_{sy}$) and the inclination of the compression struts ($\alpha$). The basic resistances $V_{R0}$ and $m_{R0}$ are then calculated. A point on the interaction diagram is obtained by dividing the required sectional resistance ($V_R = \gamma_R \gamma_S V$, $m_R = \gamma_R \gamma_S m$) by the basic resistances ($V_R/V_{R0}$, $m_R/m_{R0}$). The required reinforcement ratio $\varrho$ is then read directly from the appropriate diagram. Linear interpolation can be used between the curves plotted on a given diagram and between any two diagrams.

8.24

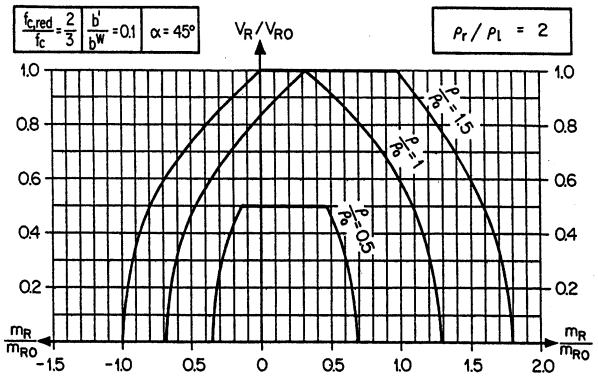



**Figure 5.61**
Shear-transverse bending interaction diagram for $\varrho_r/\varrho_l = 2.0$

### 5.3.3 Bottom Slab

The thickness of the bottom slab near the supports is determined from structural behaviour. Away from the supports, it is normally governed by detailing and construction requirements. Ductile behaviour is ensured when the axial resistance of the bottom slab, neglecting any contribution from the webs, is greater than the yield force of the girder reinforcement at the support. Conservatively chosen bottom slab dimensions in the support region will result in no significant increase in overall cost, since the moments produced by the additional weight will be small. Away from the supports, the bottom slab should be at least 0.15 m thick, to enable proper placement and vibration of the concrete, and to minimize differential shrinkage and temperature strains in the girder.

In regions of high shear, high diagonal compressive forces will be induced in the bottom slab near the slab-web junction. Haunching the bottom slab is recommended to reduce the accompanying diagonal compressive stresses. The required haunch thickness can be calculated from the state of equilibrium shown in figure 5.62. The diagonal compressive force per unit length, $\bar{D}$, is expressed as a function of shear stress at the slab-web interface, $\tau$, and bottom-slab thickness $t^{bs}$:

$$\bar{D} = \frac{V}{\cos\alpha} = \frac{\tau t^{bs}}{\cos\alpha} \qquad \text{(a)}$$

The diagonal compressive stress in the concrete is limited to $f_{c,\mathrm{red}}$:

$$\frac{\bar{D}}{t^{bs}\sin\alpha} \leq f_{c,\mathrm{red}} \qquad \text{(b)}$$



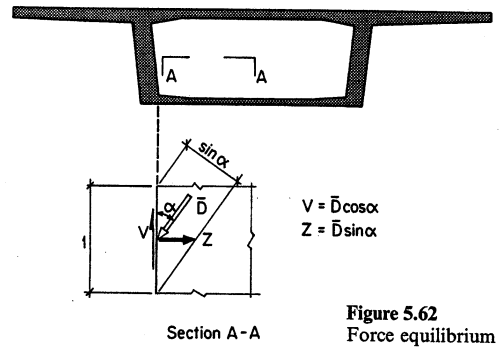



**Figure 5.62**
Force equilibrium at the bottom slab-web connection

Substitution of equation (a) into equation (b) yields the following expression for the maximum allowable shear stress at the slab-web interface, $\tau_{\max}$:

$$\tau_{\max} = f_{c,\mathrm{red}} \sin\alpha \cos\alpha \qquad \text{(c)}$$

Equation (c) is used to formulate an expression for the required bottom slab thickness in terms of the ultimate shear flow at the slab-web interface $v^* = \gamma_R \gamma_S v$:

$$t^{bs}_{\mathrm{req}} = \frac{v^*}{\tau_{\max}} = \frac{v^*}{f_{c,\mathrm{red}} \sin\alpha \cos\alpha}$$

($f_{c,\mathrm{red}}$ is a function of $\alpha_0$, the inclination angle of the principal stresses, assuming homogeneous elastic behaviour:

$$f_{c,\mathrm{red}} = f_c\left(1 - 0.3\,\frac{\alpha_0}{45°}\right) \qquad \text{(equation (4.4))}$$

Since the normal stress in the transverse direction $\sigma_y$ is very small, $\alpha_0$ can be calculated from the ultimate longitudinal normal stress $\sigma_x^* = \gamma_R \gamma_S \sigma_x$ and the ultimate shear stress $\tau_{xy}^* = \gamma_R \gamma_S \tau_{xy}$, using the equation $\tan 2\alpha_0 = 2\tau_{xy}^*/\sigma_x^*$.)

The reinforcement necessary to resist the corresponding transverse tension $Z$ is designed using the equation

$$A_s = \frac{s v^* \tan\alpha}{f_{sy}}$$

This reinforcement can be arranged according to the actual shear flow, decreasing away from the region of maximum shear. Proper anchorage of the bars into the webs is of utmost importance, since the stress in the reinforcement due to both shear and transverse bending will be highest at the slab-web interface.

8.2/10

Menn

SUMMARY

The research project "Shear with Transverse Bending", performed at the Institute of Structural Engineering, Swiss Federal Institute of Technology (ETH) Zurich, covered detailed studies on the behavior of beams of which the webs were loaded under combined shear and transverse bending. The transverse bending was constant along the beams. The studies were based on a test series of six I-shaped reinforced concrete beams. Each beam was tested with two different load arrangements.

The aim of the research project was to analyse the following two problems:
- Design of the shear reinforcement
- Determination of the upper limit of shear stresses

The principal parameters were composed of characteristic values of shear (stirrup reinforcement, longitudinal reinforcement and inclination of the concrete struts) and of characteristic values of transverse bending (intensity of transverse bending, ratio of the stirrup reinforcement in the tension zone and compression zone of the web).

The parameters were chosen in such a way that the ultimate load of the test beams was reached after yielding of the reinforcement (ductile behavior) with the first load arrangement and after crushing of the concrete (brittle failure) with the second load arrangement.

The test results may be summarized as follows:
If the beam shows a ductile behavior the ultimate shear force is not influenced by transverse bending as far as the shear force may be shifted towards the compression zone of the web without distrubing equilibrium. A full interaction between shear force and transverse bending can be observed; i.e. the web reinforcement has to be designed only for the dominant of the two loadings. Under service load the stirrup stresses in the tension zone of the web are essentially lower than expected according to the superposition of shear and transverse bending because the shear force is shifted towards the compression zone. The crack pattern may be influenced favorably with struts inclined at about $45^{o}$ or with an asymmetric web reinforcement.

If the beam shows a brittle failure the ultimate shear force decreases substantially as far as the transverse bending moment exceeds the cracking moment. The rather small number of tests does not allow the exact determination of the upper limit of shear stresses because a large variation of the test results is possible. However, the calculated shear stresses of transverse bent webs should not exceed 60% of the upper limit fixed for pure shear.

8.2/12

# Versuche über Schub bei Querbiegung

von

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Institut für Baustatik und Konstruktion
Eidgenössische Technische Hochschule Zürich

Zürich
Dezember 1976

8.2/13



When welded wire reinforcement is used as transverse reinforcement, it shall be anchored at both ends in accordance with Article 5.11.2.6.3. No welded joints other than those required for anchorage shall be permitted.

Components of inclined flexural compression and/or flexural tension in variable depth members shall be considered when calculating shear resistance.

### 5.8.2.9 Shear Stress on Concrete

The shear stress on the concrete shall be determined as:

$$v_u = \frac{|V_u - \phi V_p|}{\phi b_v d_v} \qquad (5.8.2.9\text{-}1)$$

where:

$b_v$ = effective web width taken as the minimum web width, measured parallel to the neutral axis, between the resultants of the tensile and compressive forces due to flexure, or for circular sections, the diameter of the section, modified for the presence of ducts where applicable (in.)

$d_v$ = effective shear depth taken as the distance, measured perpendicular to the neutral axis, between the resultants of the tensile and compressive forces due to flexure; it need not be taken to be less than the greater of 0.9 $d_e$ or 0.72$h$ (in.)

$\phi$ = resistance factor for shear specified in Article 5.5.4.2

In determining the web width at a particular level, one-half the diameters of ungrouted ducts or one-quarter the diameter of grouted ducts at that level shall be subtracted from the web width.

The components in the direction of the applied shear of inclined flexural compression and inclined flexural tension can be accounted for in the same manner as the component of the longitudinal prestressing force, $V_p$.

### C5.8.2.9

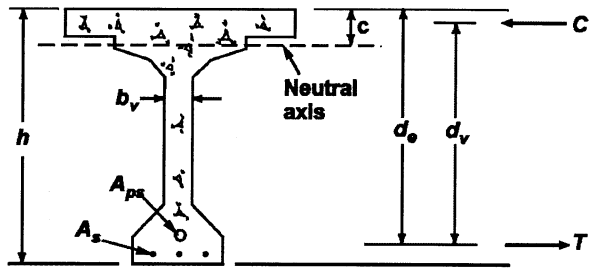


**Figure C5.8.2.9-1 Illustration of the Terms $b_v$ and $d_v$.**

For flexural members, the distance between the resultants of the tensile and compressive forces due to flexure can be determined as:

$$d_v = \frac{M_n}{A_s f_y + A_{ps} f_{ps}} \qquad (C5.8.2.9\text{-}1)$$

In continuous members near the point of inflection, if Eq. C1 is used, it should be evaluated in terms of both the top and the bottom reinforcement. Note that other limitations on the value of $d_v$ to be used are specified.

Previous editions of these Standard Specifications permitted $d$ for prestressed members to be taken as 0.8$h$. The 0.72$h$ limit on $d_v$ is 0.9 × 0.8$h$.

Post-tensioning ducts act as discontinuities and hence, can reduce the crushing strength of concrete webs. In determining which level over the effective depth of the beam has the minimum width, and hence controls $b_v$, levels which contain a post-tensioning duct or several ducts shall have their widths reduced. Thus, for the section shown in Figure C1, the post-tensioning duct in the position shown would not reduce $b_v$, because it is not at a level where the width of the section is close to the minimum value. If the location of the tendon was raised such that the tendon is located within the narrow portion of the web, the value of $b_v$ would be reduced.

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# 8.3 Initial Review of Transverse Analysis

## 8.3 Initial Review of Transverse Analysis

Job CLINE AVENUE LOAD RATING Project No. ____
Description TRANSVERSE ANALYSIS Computed by PT Date 1/12/09
Checked by DLM Date 1/13/09
Reference

Live load case HL93 + Permit.

The following was considered ONLY for the live load case when a design/permit load and an HL93 loading were combined, Michigan truck Train No. 5 and No 8 which are labeled as trucks R4 and R5, and the special INDOT permit trucks (S1 thru S5).

1.- Consider the following Brug runs.

Case ① two HL93 Trucks.

Case ② One HL93 Truck.

Case ③ Two HL93 Tandem.

Case ④ One HL93 Tandem.

Case ⑤ Two Permit truck } $R_4$, $R_5$
Case ⑥ One Permit truck } $S_1$, $S_2$, $S_3$, $S_4$ and $S_5$

2.- Check if one permit truck control over two permit truck

If $abs(M_{Two\ truck}) > abs(M_{one\ truck})$, then two truck contro

3.- If one truck control

$M_{Design} = M_{one\ truck}$.

**URS**

8.3/3 4.2/8

Page ____ of ____

Job CLINE AVENUE LOAD RATING Project No. ____ Sheet ____ of ____

Description TRANSVERSE ANALYSIS Computed by PT Date 1/12/09

Checked by DHM Date 1/13/09

Reference

4 – If two truck controls

$M_{Design}$ = Maximum of the following:

one HL93 case ② + (2S3 case ⑤ − 1S3 case ⑥): 10.218 + (29.637 − 29.59) 0.983

one S3 case ⑥ + (2HL93 case ① − 1HL93 case ②): 29.59 + (11.201 − 10.218) 30.573

One Tan case ④ + (2S3 case ⑤ − 1S3 case ⑥): 8.861 + (29.637 − 29.59) 1.024

one S3 case ⑥ + (2Tan case ③ − 1Tan case ④): 29.59 + (9.885 − 8.861) 30.614

on

1 Lane S3

14.962 − 13.959

29.637 − 25.055

129

6.265 Tandem 6.201

−3.546

Δ = 4.936

−5.528 11.201 −9.074

Δ = 3.684

−5.209 9.885 −7.799

2.59

VEH: HL93 TRUCK - S BRUG(5.75.43) page 52
date 15/01/2009; time 10:50:56
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0217 | -2.5556 | 0.0011 | 0.2970 |
| | 19.250 | -0.0295 | -4.2612 | 0.0018 | 0.1617 |
| | 36.167 | -0.0692 | -5.0781 | -0.0189 | -0.0910 |
| | 54.941 | 0.0752 | 4.5336 | -0.0196 | -0.4529 |
| | 73.174 | 0.0414 | 6.2270 | -0.0032 | -0.5297 |
| 12 | 87.340 | 0.0430 | 6.1827 | -0.0038 | -0.5129 |
| Area | | 0.4418 | 36.5046 | -1.0146 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 10.218 | -5.528 | -3.146 | -1.290 |
| Total | 21.249 | 5.502 | -6.686 | -4.830 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
48.94 50.44 54.94 56.44

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

VEH: HL93- TANDEM - BRUG(5.75.43) page 52
date 15/01/2009; time 10:50:55
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0228 | -2.5556 | 0.0008 | 0.2970 |
| | 19.250 | -0.0282 | -4.2612 | 0.0028 | 0.1617 |
| | 36.167 | -0.0978 | -5.0781 | -0.0370 | -0.0910 |
| | 54.941 | 0.1063 | 4.5336 | -0.0379 | -0.4529 |
| | 73.174 | 0.0408 | 6.2270 | -0.0027 | -0.5297 |
| 12 | 87.340 | 0.0439 | 6.1827 | -0.0040 | -0.5129 |
| Area | | 0.5667 | 36.5046 | -1.6340 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 8.861 | -5.209 | -3.111 | -2.144 |
| Total | 19.891 | 5.821 | -6.651 | -5.684 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
50.21 51.71 56.21 57.71

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
31.54 33.04 37.54 39.04

8.3/6



VEH: S3 - SPECIAL TR BRUG(5.75.43) page 52
date 15/01/2009; time 10:51:00
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0142 | -2.5556 | 0.0014 | 0.2970 |
| | 19.250 | -0.0225 | -4.2612 | 0.0010 | 0.1617 |
| | 36.167 | -0.0332 | -5.0781 | -0.0035 | -0.0910 |
| | 54.941 | 0.0325 | 4.5336 | -0.0054 | -0.4529 |
| | 73.174 | 0.0324 | 6.2270 | -0.0027 | -0.5297 |
| 12 | 87.340 | 0.0323 | 6.1827 | -0.0027 | -0.5129 |
| Area | | 0.2289 | 36.5046 | -0.2144 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 29.590 | -13.959 | -2.817 | -1.091 |
| Total | 40.620 | -2.929 | -6.357 | -4.632 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
58.17 59.67 64.17 65.67

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

VEH: HL93 TRUCK BRUG(5.75.43) page 52
date 15/01/2009; time 10:51:02
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0217 | -2.5556 | 0.0011 | 0.2970 |
| | 19.250 | -0.0295 | -4.2612 | 0.0018 | 0.1617 |
| | 36.167 | -0.0692 | -5.0781 | -0.0189 | -0.0910 |
| | 54.941 | 0.0752 | 4.5336 | -0.0196 | -0.4529 |
| | 73.174 | 0.0414 | 6.2270 | -0.0032 | -0.5297 |
| 12 | 87.340 | 0.0430 | 6.1827 | -0.0038 | -0.5129 |
| Area | | 0.4418 | 36.5046 | -1.0146 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 11.201 | -9.074 | -3.449 | -3.254 |
| Total | 22.231 | 1.956 | -6.989 | -6.794 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
48.94 50.44 54.94 56.44
58.94 60.44 64.94 66.44

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
24.67 26.17 30.67 32.17
34.67 36.17 40.67 42.17

VEH: HL93- TANDEM BRUG(5.75.43) page 52
date 15/01/2009; time 10:51:01
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0228 | -2.5556 | 0.0008 | 0.2970 |
| | 19.250 | -0.0282 | -4.2612 | 0.0028 | 0.1617 |
| | 36.167 | -0.0978 | -5.0781 | -0.0370 | -0.0910 |
| | 54.941 | 0.1063 | 4.5336 | -0.0379 | -0.4529 |
| | 73.174 | 0.0408 | 6.2270 | -0.0027 | -0.5297 |
| 12 | 87.340 | 0.0439 | 6.1827 | -0.0040 | -0.5129 |
| Area | | 0.5667 | 36.5046 | -1.6340 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 9.885 | -7.799 | -4.047 | -2.837 |
| Total | 20.915 | 3.231 | -7.587 | -6.378 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
48.71 50.21 54.71 56.21
58.71 60.21 64.71 66.21

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
23.04 24.54 29.04 30.54
33.04 34.54 39.04 40.54

8.3/9



VEH: S3 - SPECIAL TR BRUG(5.75.43) page 52
date 15/01/2009; time 10:51:06
Cline Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0142 | -2.5556 | 0.0014 | 0.2970 |
| | 19.250 | -0.0225 | -4.2612 | 0.0010 | 0.1617 |
| | 36.167 | -0.0332 | -5.0781 | -0.0035 | -0.0910 |
| | 54.941 | 0.0325 | 4.5336 | -0.0054 | -0.4529 |
| | 73.174 | 0.0324 | 6.2270 | -0.0027 | -0.5297 |
| 12 | 87.340 | 0.0323 | 6.1827 | -0.0027 | -0.5129 |
| Area | | 0.2289 | 36.5046 | -0.2144 | -16.6877 |

| Description | Moment Max. | Moment Min. | Axial force Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 8.549 | 8.549 | -3.025 | -3.025 |
| Topping | 0.913 | 0.913 | -0.417 | -0.417 |
| Linear loads | 1.568 | 1.568 | -0.098 | -0.098 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 29.637 | -25.055 | -2.824 | -0.814 |
| Total | 40.667 | -14.025 | -6.364 | -4.354 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
58.17 59.67 64.17 65.67
68.17 69.67 74.17 75.67

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
20.17 21.67 26.17 27.67
30.17 31.67 36.17 37.67

On-

| Section | Spans | Depth 1 | Depth 2 | Web | Span 1 (feet) | Span 2 (feet) | Span 3 (feet) | Span 4 (feet) | Span 5 (feet) | Span 6 (feet) | Span 7 (feet) | Total (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IA | 7 | 0.75 | 1.67 | 1.17 | 11.00 | 15.83 | 20.92 | 15.83 | 20.92 | 15.83 | 11.00 | 111.33 |
| IIA | 4 | 0.75 | 1.50 | 1.29 | 7.31 | 16.85 | 16.85 | 7.31 | | | | 48.33 |
| IIB | 4 | 0.75 | 1.67 | 1.17 | 11.00 | 16.92 | 16.92 | 10.79 | | | | 55.63 |
| IIIA | 5 | 0.75 | 1.67 | 1.17 | 10.79 | 15.83 | 14.81 | 15.83 | 6.85 | | | 64.12 |
| IIIB | 5 | 0.75 | 1.67 | 1.17 | 10.79 | 16.08 | 22.40 | 16.08 | 6.25 | | | 71.60 |
| IVA | 6 | 0.75 | 1.67 | 1.17 | 10.79 | 16.92 | 16.92 | 20.63 | 15.83 | 6.25 | | 87.34 |
| VA | 3 | 0.75 | 1.50 | 1.29 | 6.31 | 15.71 | 6.31 | | | | | 28.33 |
| VB | 3 | 0.75 | 1.50 | 1.29 | 7.31 | 26.37 | 7.31 | | | | | 41.00 |
| VC | 2 | 0.75 | 1.67 | 1.17 | 15.83 | 6.25 | | | | | | 22.08 |

8.3/10

| Section | AASHTO Lanes Rating Factor Inventory HL93 | AASHTO Lanes Rating Factor Operating HL93 | AASHTO Lanes Rating Factor Operating Legal | AASHTO Lanes Rating Factor Operating Permit | Striped Lanes Rating Factor Inventory HL93 | Striped Lanes Rating Factor Operating HL93 | Striped Lanes Rating Factor Operating Legal | Striped Lanes Rating Factor Operating Permit |
|---|---|---|---|---|---|---|---|---|
| IA | 0.60 | 0.78 | 0.69 | 0.43 | 0.60 | 0.78 | 0.69 | 0.43 |
| IIA | 1.09 | 1.41 | 1.46 | 1.07 | 1.09 | 1.41 | 1.46 | 1.07 |
| IIB | 1.78 | 2.30 | 2.35 | 1.80 | 1.78 | 2.30 | 2.46 | 1.91 |
| IIIA | 1.76 | 2.29 | 2.13 | 1.30 | 1.78 | 2.31 | 2.14 | 1.33 |
| IIIB | 0.93 | 1.20 | 1.28 | 0.91 | 0.93 | 1.20 | 1.28 | 0.91 |
| IVA | 1.10 | 1.43 | 1.51 | 0.92 | 1.10 | 1.43 | 1.51 | 1.12 |
| VA | 1.24 | 1.61 | 1.88 | 1.46 | 1.24 | 1.61 | 1.88 | 1.71 |
| VB | 0.89 | 1.16 | 1.24 | 1.00 | 0.89 | 1.16 | 1.24 | 1.00 |
| VC | 1.58 | 2.05 | 2.05 | 1.34 | 1.61 | 2.09 | 2.10 | 1.47 |

8.3/11

| Section | AASHTO Lanes Reinforcing Top Total | AASHTO Lanes Reinforcing Top Dead Load | AASHTO Lanes Reinforcing Middle Total | AASHTO Lanes Reinforcing Middle Dead Load | Striped Lanes Reinforcing Top Total | Striped Lanes Reinforcing Top Dead Load | Striped Lanes Reinforcing Middle Total | Striped Lanes Reinforcing Middle Dead Load |
|---|---|---|---|---|---|---|---|---|
| IA | 0.49 | 0.16 | 0.27 | 0.10 | 0.44 | 0.16 | 0.23 | 0.10 |
| IIA | 0.30 | 0.08 | 0.12 | 0.05 | 0.30 | 0.08 | 0.11 | 0.05 |
| IIB | 0.65 | 0.21 | 0.35 | 0.13 | 0.35 | 0.21 | 0.19 | 0.13 |
| IIIA | 0.49 | 0.15 | 0.27 | 0.10 | 0.40 | 0.15 | 0.19 | 0.10 |
| IIIB | 0.47 | 0.14 | 0.25 | 0.09 | 0.45 | 0.14 | 0.24 | 0.09 |
| IVA | 0.80 | 0.24 | 0.44 | 0.14 | 0.79 | 0.24 | 0.44 | 0.14 |
| VA | 0.14 | 0.04 | 0.06 | 0.04 | 0.11 | 0.04 | 0.04 | 0.04 |
| VB | 0.37 | 0.02 | 0.13 | 0.03 | 0.37 | 0.02 | 0.13 | 0.03 |
| VC | 0.65 | 0.09 | 0.33 | 0.04 | 0.58 | 0.09 | 0.31 | 0.04 |

$$\frac{0.31 \ \frac{in^2}{ft}}{1.5 \ ft} = 0.207 \ in^2/ft$$

$$\frac{\frac{0.31 \ in^2}{ft}}{0.8333} = 0.372 \ in^2/ft$$

8.3/12

**URS**

8.3/13

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Lanes

Sect IA

Slab (Thickness Change)

| | | |
|---|---|---|
| Inventory | 0.60 | HL93 or Tandem |
| Operating | 0.78 | |
| Operating | 0.69 | INDOT LEGAL |
| " | 0.43 | INDOT Permit |

Web

| | | |
|---|---|---|
| Top | 0.49 in²/ft (Total) | S-3 |
| | 0.16 in²/ft (DL) | |
| middle | 0.27 in²/ft (Total) | |
| | 0.10 in²/ft (DL) | |

**URS**

8.3/14

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Clime Computed by RJB Date 8/27/09

Checked by ____ Date ____

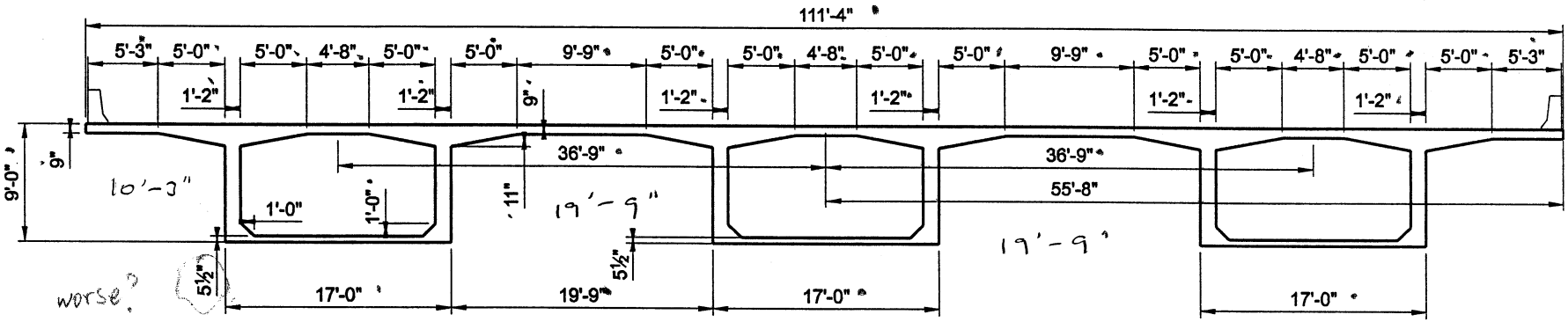
Reference

Striped Lanes

Sect IA

| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 0.60 | HL93 or Tandem | Thickness Chang |
| | Operating | 0.78 | HL93 or Tandem | " " |
| | Operating | 0.69 | Legal - R3 | Thickness Chang |
| | Operating | 0.43 | Permit - SS | " " |

| | | Reinf Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.44 $in^2/ft$ | (Total) | Permit SS-S |
| | | 0.16 | (D.L.) | |
| | middle | 0.23 | (Total) | |
| | | 0.10 | (D.L.) | |




DIMENSIONS

1/13/09

4.3.1/a

8.3/15

| HALF SIZE PRINT - 11x17 | | | | |
|---|---|---|---|---|
| | Designed by R.V.A. | URS Corporation Southern 7650 Corporate Center Drive Suite 400 Miami, FL 33126-1220 Tel: (305) 262-7485 C.A. No. EB 00000002 | TYPICAL SECTION - Transverse Analysis | SECTION IA |

**URS**

8.3/16

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Lanes

Sect IIA

Slab (Thickness Change)

| | | |
|---|---|---|
| Inventory | 1.09 | HL93 or Tandem |
| Operating | 1.41 | |
| Operating | 1.46 | INDOT Legal |
| Operating | 1.07 | Permit |

Web

| | | | |
|---|---|---|---|
| Top | 0.30 $in^2/ft$ (Tot) | | |
| | 0.08 $in^2/ft$ (DL) | Permit | |
| middle | 0.12 $in^2/ft$ (Tot) | S3 | |
| | 0.05 $in^2/ft$ (DL) | | |

**URS**

Page 8.3/17 of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by ____ Date ____

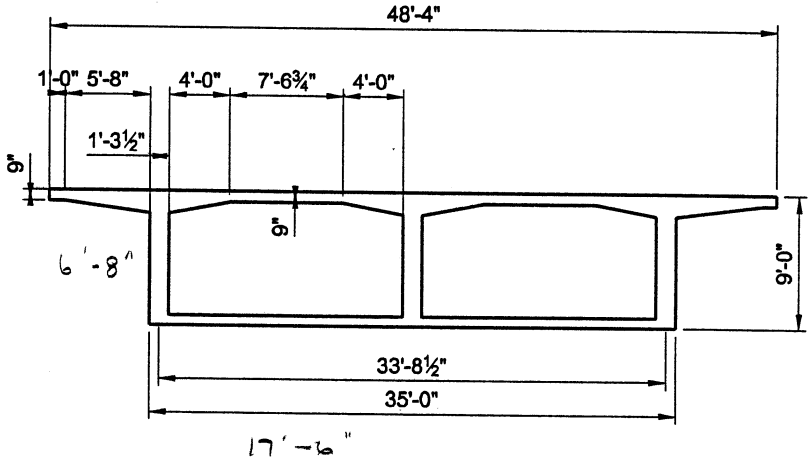
Reference

Striped Lanes

Sect II A

| | | RF | | | Thickness Change |
|---|---|---|---|---|---|
| Slab | Inventory | 1.09 | HL93 or | Tandem | |
| | Operating | 1.41 | HL93 or | Tandem | " " |
| | Operating | 1.46 | Legal - | R1 | " " |
| | Operating | 1.07 | Permit - | S3 | " " |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.30 $m^2/ft$ | (Total) | Permit S3-S |
| | | 0.08 | (D.L.) | |
| | middle | 0.11 | (Total) | |
| | | 0.05 | (D.L.) | |




DIMENSIONS

JDeen
01/14/09

8.3/8

4.4.1/3

| HALF SIZE PRINT - 11x17 | | | | |
|---|---|---|---|---|
| No. | Date | App. | Revisions | |

Designed by
Drawn by R.V.A.
Checked by
Checked by (SCALE)

URS

URS Corporation Southern
7650 Corporate Center Drive
Suite 400
Miami, FL 33126-1220
Tel: (305) 262-7460
C.A. No.: EB 00000002

TYPICAL SECTION - Transverse Analysis

SECTION IIA

Drawing No.

**URS**

83/19

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Lanes

Sect II B

| | | | | |
|---|---|---|---|---|
| Slab | Inventory | 1.78 | HL93 or Tandem | ℄ Slab |
| | Operating | 2.30 | " " " | " " |
| | Operating | 2.35 | Legal | - Crown & Slab @ Web |
| | " | 1.80 | Permit | - " " " |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.65 in²/ft | (Total) | Permit S3 |
| | | 0.21 in²/ft | (DL) | |
| | middle | 0.35 in²/ft | (Total) | |
| | | 0.13 in²/ft | (DL) | |

8.3/20

**URS**

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by ____ Date ____

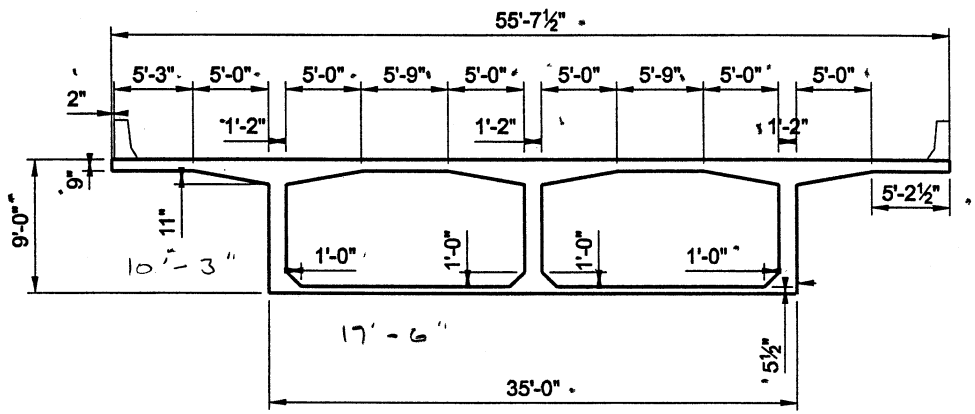
Reference

Striped Lanes

Sect IIB

| | | | | | |
|---|---|---|---|---|---|
| Slab | Inventory | 1.78 | HL93 or | Tandem | ℄ slab |
| | Operating | 2.30 | HL93 or | Tandem | " " |
| | Operating | 2.40 | Legal - | R1 | " " |
| | Operating | 1.91 | Permit - | S3 | " " |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.35 in²/ft | (Total) | Permit |
| | | 0.21 | (D.L.) | S3-S |
| | middle | 0.19 | (Total) | S5-S |
| | | 0.13 | (D.L.) | |




DIMENSIONS

✓ DLM
01/15/09

83/21
4.5.1/3

HALF SIZE PRINT - 11x17

Designed by
Drawn by R.V.A.
Checked by
Original date

URS
URS Corporation Southern
7650 Corporate Center Drive
Suite 400
Miami, FL 33126-1220
Tel: (305) 592-7400
C.A. No. EB 00000682

TYPICAL SECTION - Transverse Analysis

SECTION IIB

Drawing no.
Sheet no.

**URS**

8.3/22

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Lanes

Sect III A

| | | | | | | |
|---|---|---|---|---|---|---|
| Slab | Inventory | 1.76 | HL93 or | Tandem | ℄ Slab | |
| | Operating | 2.29 | " | " | " | " |
| | " | 2.13 | Legal | Cant & Slab @ Web | | |
| | " | 1.30 | Permit | Cant. & Slab @ Web | | |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.49 in²/ft | (Total) | Permit S3 |
| | | 0.15 in²/ft | (DL) | |
| | middle | 0.27 in²/ft | (Total) | |
| | | 0.10 in²/ft | (DL) | |

**URS**

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Page ____ of ____

Job _____ Project No. _____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by _____ Date _____

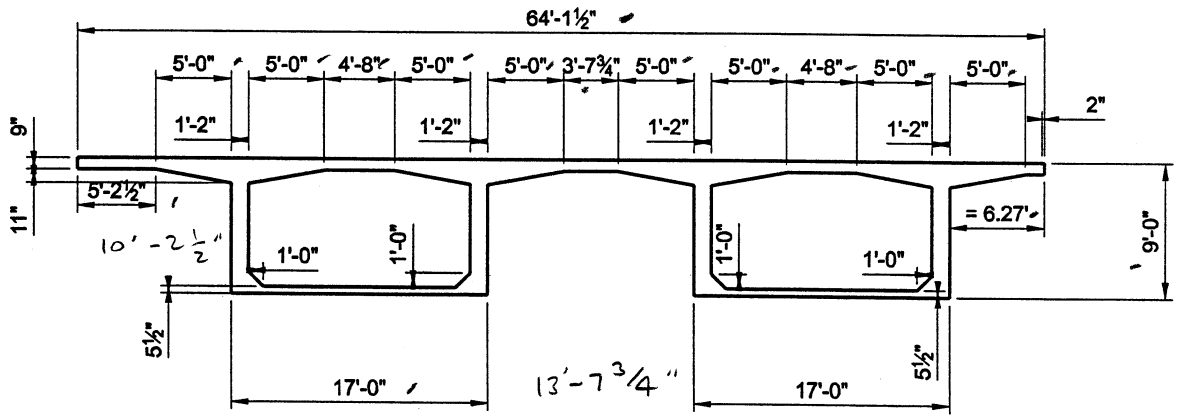
Reference

Striped Lanes

Sect III A

| | | RF | | | |
|---|---|---|---|---|---|
| Slab | Inventory | 1.78 | HL93 or | Tandem | ℄ Slab |
| | Operating | 2.31 | HL93 or | Tandem | " " |
| | Operating | 2.14 | Legal - | R3 | Cant. or Webs |
| | Operating | 1.33 | Permit - | SS | " |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.40 $in^2/ft$ | (Total) | Permit SS-S |
| | | 0.15 | (D.L.) | |
| | middle | 0.19 | (Total) | |
| | | 0.10 | (D.L.) | |




DIMENSIONS

JDCM
04/26/09

8.3/24
4.6.1/3

| HALF SIZE PRINT - 11x17 | | | | | |
|---|---|---|---|---|---|
| | Designed by | | URS | TYPICAL SECTION - Transverse Analysis | SECTION IIIA |
| | Drawn by R.V.A. | | | | |
| | Checked by | | | | |
| | ORIGINAL SCALE | | | | |

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8.3/25

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Loads

Sect III B

| | | | | | |
|---|---|---|---|---|---|
| Slab | Dimentary | 0.93 | HL93 or | Tandem | ℄ Slab |
| | Operating | 1.20 | " " | " | " " |
| | " | 1.28 | Legal | | " " |
| | " | 0.91 | Permit | | Thickness Chang |

| | | | |
|---|---|---|---|
| Web | Top | 0.47 in²/ft (Tot.) | Permit S3 |
| | | 0.14 in²/ft (DL) | |
| | middle | 0.25 in²/ft (Tot.) | |
| | | 0.09 in²/ft (DL) | |

**URS**

8.3/26

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by ____ Date ____

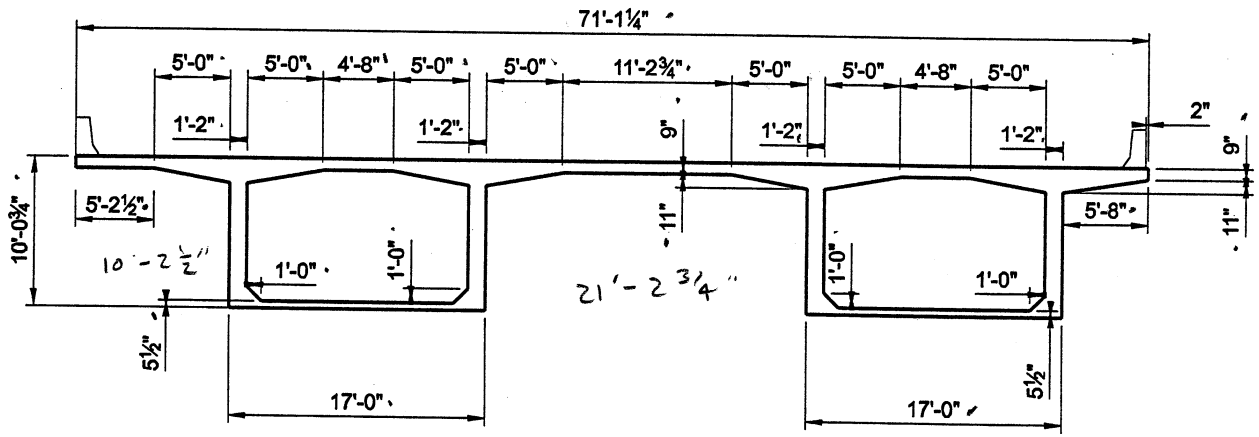
Reference

Striped Lanes

Sect IIIB

| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 0.93 | HL93 or Tandem | ℄ Slab |
| | Operating | 1.20 | HL93 or Tandem | " " |
| | Operating | 1.28 | Legal - R1 | " " |
| | Operating | 0.91 | Permit - SS | Thickness Change |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.45 in²/ft | (Total) | Permit SS-S |
| | | 0.14 | (D.L.) | |
| | middle | 0.24 | (Total) | |
| | | 0.09 | (D.L.) | |




DIMENSIONS

DEM
01/23/09
47.1/3
8.3/27

| HALF SIZE PRINT - 11x17 | | | | | |
|---|---|---|---|---|---|
| | | | URS Corporation Southern<br>7650 Corporate Center Drive<br>Suite 400<br>Miami, FL 33126-1220<br>Tel: (305) 592-2466<br>C.A. No. 8/8 00000002 | TYPICAL SECTION - Transverse Analysis | SECTION IIIB |

8.3/28

**URS**

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Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by ____ Date ____

Reference

AASHTO Lanes

Sect IVA

| | | | | |
|---|---|---|---|---|
| Slab | Inventory | 1.10 | HL93 or Tandem | ℄ slab |
| | Operating | 1.43 | " " " | |
| | " | 1.51 | Legal | |
| | " | 0.92 | Permit | Thickness Change |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.80 in²/ft | (Tot.) | S3 |
| | | 0.24 in²/ft | (DL) | |
| | middle | 0.44 in²/ft | (Tot.) | |
| | | 0.14 in²/ft | (DL) | |

8.3/29

**URS**

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by ____ Date ____

Reference

Striped Lanes

Sect IVA

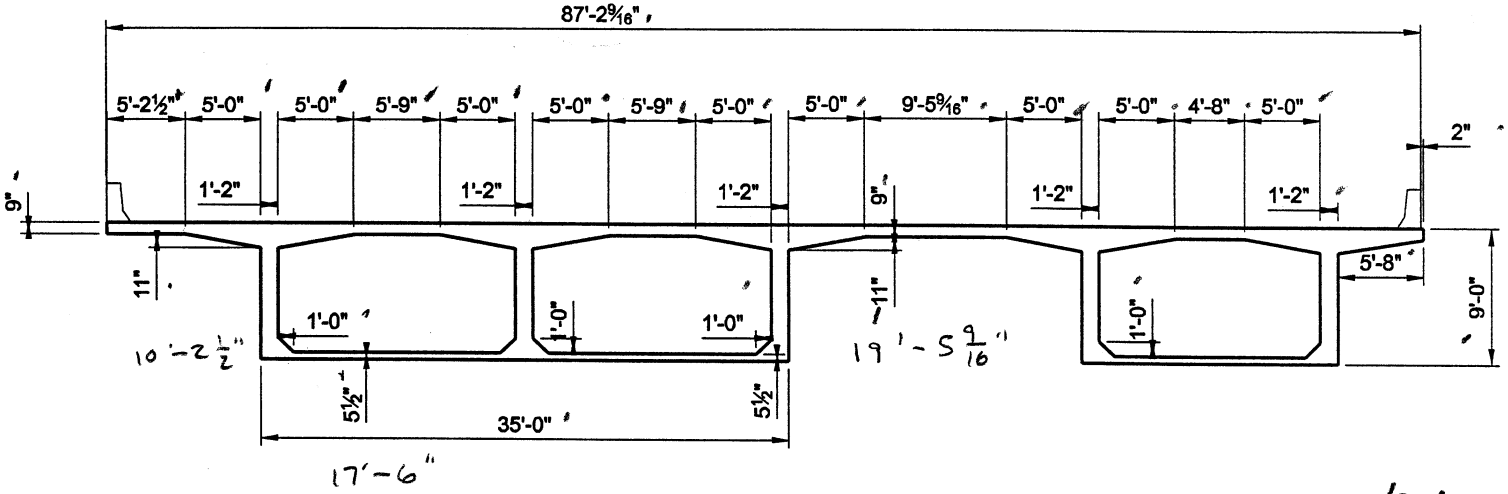
| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 1.10 | HL93 or Tandem | @ slab |
| | Operating | 1.43 | HL93 or Tandem | " " |
| | Operating | 1.51 | Legal - R1 | " " |
| | Operating | 1.12 | Permit - SS | Thickness Chng |

| | | Reinf. Req'd | |
|---|---|---|---|
| Web | Top | 0.79 in²/ft (Total) | Permit SS-S |
| | | 0.24 in²/ft (D.L.) | |
| | min LL | 0.44 in²/ft (Total) | |
| | | 0.14 in²/ft (D.L.) | |

Min LL - 2T
55

12a
DL -8.55
SDL -2.48
LL -23.50
53

-28.296 55




DIMENSIONS

Dem
1/15/09

8.3/30
4.8.1/3

HALF SIZE PRINT - 11x17

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Drawn by R.V.A.
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Drawing Scale

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TYPICAL SECTION - Transverse Analysis

SECTION IVA

DRAWING NO.

**URS**

8.3/31

Page ____ of ____

Job _____ Project No. _____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by _____ Date _____

Reference

AASHTO Lanes

Sect V A

| | | | | |
|---|---|---|---|---|
| Slab | Inventory | 1.24 | HL 93 or Tandem | ℄ slab |
| | Operating | 1.61 | | |
| | " | 1.88 | Legal | " |
| | " | 1.46 | Permit | " |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.14 in²/ft | (Total) | Permit S3 |
| | | 0.04 in²/ft | (DL) | |
| | middle | 0.06 in²/ft | (Total) | |
| | | 0.04 in²/ft | (DL) | |

**URS**



Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/27/09

Checked by ____ Date ____

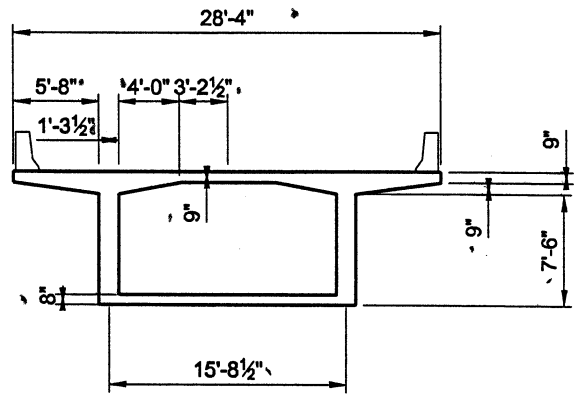
Reference

Striped Lanes

Sect VA

| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 1.24 | HL93 or Tandem | @ Slab |
| | Operating | 1.61 | HL93 or Tandem | " " |
| | Operating | 1.88 | Legal - R1 | " " |
| | Operating | 1.71 | Permit - S3 | " " |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.11 | (Total) | Permit S3-S |
| | | 0.04 | (D.L.) | |
| ? | middle | 0.04 | (Total) | |
| | | 0.04 | (D.L.) | |




DIMENSIONS

01/16/09

8.3/33
4.9.1/3

| HALF SIZE PRINT - 11x17 | | | |
|---|---|---|---|
| No. Date Rev. Revisions | Designed by<br>Drawn by R.V.A.<br>Checked by<br>Unless Noted | URS Corporation Southern<br>7650 Corporate Center Drive<br>Suite 400<br>Miami, FL 33126-1205<br>Tel. (305) 262-7400<br>C.A. No. EB 00000002 | TYPICAL SECTION - Transverse Analysis |

SECTION VA

**URS**

8.3/34

Page ____ of ____

Job _____ Project No. _____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by _____ Date _____

Reference

AASHTO Lanes

Sect V B

| | | | | |
|---|---|---|---|---|
| Slab | Inventory | 0.89 | HL93 or Tandem | ℄ Slab |
| | Operating | 1.16 | | |
| | " | 1.24 | Legal | " |
| | " | 1.00 | Permit | " |

| | | | |
|---|---|---|---|
| Web | Top | 0.37 $in^2/ft$ | Permit S3 |
| | | 0.02 $in^2/ft$ | |
| | Bot | 0.13 $in^2/ft$ | |
| | | 0.03 $in^2/ft$ | |

**URS**

8.3/35

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description Clime Computed by RJB Date 8/27/09

Checked by ____ Date ____

Reference

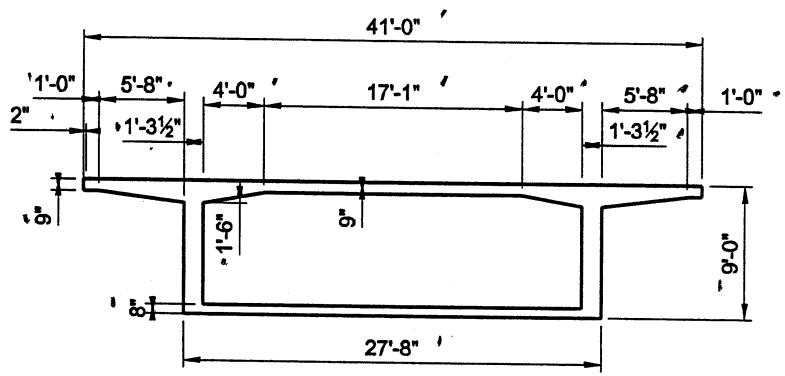
Striped Lanes

Sect VB

| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 0.89 | HL93 or Tandem | @ Slab |
| | Operating | 1.16 | HL93 or Tandem | @ Slab |
| | Operating | 1.24 | Legal - R1 | " " |
| | Operating | 1.00 | Permit - S3 | " " |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.37 | (Total) | Permit S3-S |
| | | 0.02 | (D.L.) | |
| | middle | 0.13 | (Total) | |
| | | 0.03 | (D.L.) | |

?




27'-8"

DIMENSIONS

√ DKM
01/16/09

4.10.1/3
8.3/3b

| HALF SIZE PRINT - 11x17 | | | | |
|---|---|---|---|---|
| Designed by | | | | |
| Drawn by R.V.A. | | | | |
| Checked by | | | | |
| Unless Noted Scale | | | | |
| No. Date Rev. | Description | | | |

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TYPICAL SECTION - Transverse Analysis

SECTION VB

**URS**



Job _____ Project No. _____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/25/09

Checked by _____ Date _____

Reference

AASHTO Lanes

Sect VC

| | | | | |
|---|---|---|---|---|
| Slab | Inventory | 1.58 | HL93 or Tandem | ℄ slab |
| | Operating | 2.05 | | |
| | " | 2.05 | Legal | " |
| | " | 1.34 | Permit | Thickness Change |

| | | | | |
|---|---|---|---|---|
| Web | Top | 0.65 in²/ft (Tot.) | Permit SS | |
| | | 0.09 in²/ft (DL) | | |
| | middle | 0.33 in²/ft (Tot.) | | |
| | | 0.04 in²/ft (DL) | | |

**URS**



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Job ____ Project No. ____ Sheet ____ of ____

Description Clime Computed by RJB Date 8/27/09

Checked by ____ Date ____

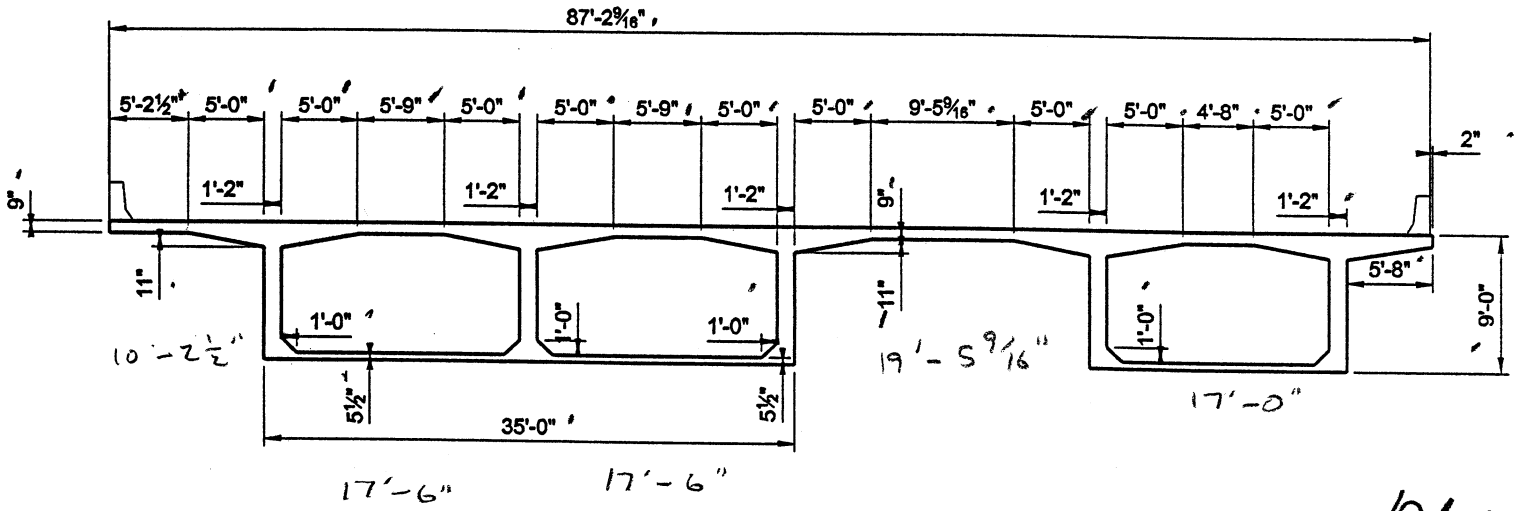
Reference

Striped Lanes

Sect VC

| | | RF | | |
|---|---|---|---|---|
| Slab | Inventory | 1.61 | HL93 or Tandem | ℄ Slab |
| | Operating | 2.09 | HL93 or Tandem | " " |
| | Operating | 2.10 | Legal - R1 | " " |
| | Operating | 1.47 | Permit - | Thickness Change |

| | | Reinf. Req'd | | |
|---|---|---|---|---|
| Web | Top | 0.58 | (Total) | Permit SS-S |
| | | 0.09 | (D.L.) | |
| | middle | 0.31 | (Total) | |
| | | 0.04 | (D.L.) | |




DIMENSIONS

DLM
1/15/09

8.3/39
4.8.1/3

HALF SIZE PRINT - 11x17

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URS

TYPICAL SECTION - Transverse Analysis

SECTION IVA
VC

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM - SINGLE VEHICLE
* code 1001
Cline Avenue - Load Rating - Double Box Mainline - 4 Webs - 55.625' Wide
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0      250.0    55.625    1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     48.958    10.000
* code 1007, linear loads
0.7350    0.441
54.890    0.441
* code 1201
    8    5    4    2    3
* code 1202 coordinates
 0.0000    0.0000    11.00
11.0000    0.0000
11.0000   -7.9375    16.92
27.9167    0.0000
27.9167   -7.9375    16.92
44.8333    0.0000
44.8333   -7.9375    10.79
55.6250    0.0000
```

Asymmetry

8.3 / 40

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM- SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Double Box - 4 Webs - 64.125' Wide
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0     250.0     64.1250   1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     57.458    10.000
* code 1007, linear loads
0.7350    0.441
63.39     0.441
* code 1201
   10    6    5    2    4
* code 1202 coordinates
0.0000    0.0         10.79
10.7917   0.0
10.7917   -7.9375
26.6250   0.0         15.83
26.6250   -7.9375
41.4383   0.0         14.81
41.4383   -7.9375
57.2717   0.0         15.83
57.2717   -7.9375
64.1250   0.0         6.85
```

A symmetry

8.3/41

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM- SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Double Box - 4 Webs - 71.105' Wide - Single Vehicle
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0     250.0     71.1050   1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     64.438    10.000
* code 1007, linear loads
0.7350    0.441
70.37     0.441
* code 1201
   10    6    5    2    4
* code 1202 coordinates
0.0000    0.0        10.79
10.7917   0.0
10.7917   -9.0005
26.6250   0.0        15.83
26.6250   -9.0005
49.0217   0.0        22.40
49.0217   -9.0005
64.8550   0.0        15.83
64.8550   -9.0005
71.1050   0.0        6.25
```

Asymmetry

83/42

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM - Single Vehicle
* code 1001
Cline Avenue - Load Rating - Double Box  AND SINGLE BOX  - 87.34' WIDE
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0      250.0        87.34       1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667      80.673   10.000
* code 1007, linear loads
0.7350    0.441
86.605    0.441
* code 1201
   12    8    6    3    5
* code 1202 coordinates
0.0000    0.0       10.79
10.7917   0.0
10.7917   -7.938    16.92
27.7083   0.0
27.7083   -7.938    16.92
44.6250   0.0
44.6250   -7.938    20.63
65.2569   0.0
65.2569   -7.938    15.83
81.0903   0.0
81.0903   -7.938
87.3403   0.0       6.25
```

Asymmetry

8.3/43

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM - SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Triple Box - 6 Webs - 111'-4" Wide
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0     250.0     111.33    1.0       1.0       1.3
* code 1004
    1    0    3
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     104.667   10.000
* code 1007, linear loads
0.7350    0.441
55.665    0.992
110.5983  0.441
* code 1201
   14    6    7    3    6
* code 1202 coordinates
0.0000    0.0
11.0000   0.0        11.00
11.0000   -7.938     15.83
26.8333   0.0
26.8333   -7.938
47.7500   0.0        20.92
47.7500   -7.938
63.5833   0.0        15.83
63.5833   -7.938
84.5000   0.0
84.5000   -7.938     20.92
100.3333  0.0
100.3333  -7.938     15.83
111.33    0.0
                     11.00
```

Symmetry

8.3/44

```
* start ; column 11-30 can be used to have your own text on the top of each page
*    5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
*    V     V     V     V     V     V     V     V     V     V     V     V     V     V     V     V
00001  1 1      VEH: HL93- TANDEM - SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Double Box - 3 Webs - 48'-4" Wide
* code 1002
    2         1
* code 1003
*    5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
*    V     V     V     V     V     V     V     V     V     V     V     V     V     V     V     V
250.0       250.0       48.33     1.0        1.0        1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667      41.667     10.000
* code 1007, linear loads
0.7350     0.441
47.5983    0.441
* code 1201
    8    5    4    2    3
* code 1202 coordinates
 0.0000    8.2500     7.31
 7.3125    8.2500
 7.3125    0.3333     16.85
24.1667    8.2500
24.1667    0.3333     16.85
41.0208    8.2500
41.0208    0.3333
48.3333    8.2500     7.31
```

Symmetry

8.3/45

```
* start ; column 11-30 can be used to have your own text on the top of each page
*    5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
*    V     V     V     V     V     V     V     V     V     V     V     V     V     V     V     V
00001  1 1      VEH: HL93- TANDEM - SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Single Box 28'-4" Wide
* code 1002
    2         1
* code 1003
*    5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
*    V     V     V     V     V     V     V     V     V     V     V     V     V     V     V     V
250.0      250.0      28.33     1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     21.667    10.000
* code 1007, linear loads
0.7350    0.441
27.5983   0.441
* code 1201
    6    5    3    1    2
* code 1202 coordinates
 0.0000   8.2500      6.31
 6.3125   8.2500
 6.3125   0.3333      15.71
22.0208   8.2500
22.0208   0.3333
28.3333   8.2500      6.31
```

Symmetry

8.3/46

```
* start ; column 11-30 can be used to have your own text on the top of each page
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
00001  1 1     VEH: HL93- TANDEM - SINGLE TRUCK
* code 1001
Cline Avenue - Load Rating - Single Box 41' Wide
* code 1002
    2         1
* code 1003
*   5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
*   V    V    V    V    V    V    V    V    V    V    V    V    V    V    V    V
250.0      250.0      41.00    1.0       1.0       1.3
* code 1004
    1    0    2
* code 1005
   50    1
* code 1005a
* location traffic lanes
7.667
* maximum and minimum truck
6.667     34.333    10.000
* code 1007, linear loads
0.7350    0.441
40.2650   0.441
* code 1201
    6    5    3    1    2
* code 1202 coordinates
 0.0000   8.2500    7.31
 7.3125   8.2500
 7.3125   0.3333    26.35
33.6875   8.2500
33.6875   0.3333
41.0000   8.2500    7.31
```

Symmetry

8.3/47

URS

PROJECT: Cline Avenue-Triple Cell - 6 Web Box, 111.33' Wide (Case I-A)
DESCRIPTION: Striped Lanes - Transverse Analysis
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.18 | 0.10 | 0.31 | 0.16 |
| HL-93 | Operating | HL-93 Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| R1 | Operating | R1 Operating | 0.17 | 0.10 | 0.28 | 0.16 |
| R1-s | Operating | R1-s Operating | 0.17 | 0.10 | 0.28 | 0.16 |
| R2 | Operating | R2 Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| R3 | Operating | R3 Operating | 0.15 | 0.10 | 0.29 | 0.16 |
| R3-s | Operating | R3-s Operating | 0.15 | 0.10 | 0.29 | 0.16 |
| R4 | Operating | R4 Operating | 0.16 | 0.10 | 0.29 | 0.16 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.10 | 0.29 | 0.16 |
| R5 | Operating | R5 Operating | 0.17 | 0.10 | 0.31 | 0.16 |
| R5-s | Operating | R5-s Operating | 0.17 | 0.10 | 0.31 | 0.16 |
| S1 | Operating | S1 Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S1-s | Operating | S1-s Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S2 | Operating | S2 Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S2-s | Operating | S2-s Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S3 | Operating | S3 Operating | 0.20 | 0.10 | 0.39 | 0.16 |
| S3-s | Operating | S3-s Operating | 0.20 | 0.10 | 0.39 | 0.16 |
| S4 | Operating | S4 Operating | 0.18 | 0.10 | 0.32 | 0.16 |
| S4-s | Operating | S4-s Operating | 0.18 | 0.10 | 0.32 | 0.16 |
| S5 | Operating | S5 Operating | 0.19 | 0.10 | 0.38 | 0.16 |
| S5-s | Operating | S5-s Operating | 0.19 | 0.10 | 0.38 | 0.16 |

#5 @ 18"

0.21 $in^2/ft$

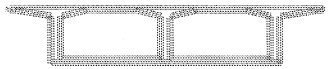
8.3/48

URS

PROJECT: **Double Cell - Three Web Box, 48'-4" Wide ( Ramps - Case II-A)** CALCS BY: PT DATE: 10/6/09

DESCRIPTION: **Superstructure - Transverse Analysis Cline Avenue** CHECKED BY: DATE:

**Area of Steel Requirements**



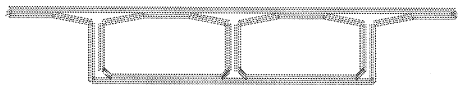
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.09 | 0.05 | 0.25 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| R1 | Operating | R1 Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R2 | Operating | R2 Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| R3 | Operating | R3 Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| R4 | Operating | R4 Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R5 | Operating | R5 Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| S1 | Operating | S1 Operating | 0.07 | 0.05 | 0.21 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.07 | 0.05 | 0.21 | 0.07 |
| S2 | Operating | S2 Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| S3 | Operating | S3 Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S4 | Operating | S4 Operating | 0.07 | 0.05 | 0.16 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.07 | 0.05 | 0.16 | 0.07 |
| S5 | Operating | S5 Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |

URS

PROJECT: Double Cell - Three Web Box - 55.625' Wide (Mainline - Case II-B
DESCRIPTION: STRIPED LANES - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

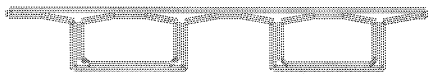
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.16 | 0.12 | 0.28 | 0.20 |
| HL-93 | Operating | HL-93 Operating | 0.15 | 0.12 | 0.26 | 0.20 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.12 | 0.26 | 0.20 |
| R1 | Operating | R1 Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R1-s | Operating | R1-s Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R2 | Operating | R2 Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R3 | Operating | R3 Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R3-s | Operating | R3-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R4 | Operating | R4 Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R5 | Operating | R5 Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R5-s | Operating | R5-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| S1 | Operating | S1 Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S1-s | Operating | S1-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S2 | Operating | S2 Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S2-s | Operating | S2-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S3 | Operating | S3 Operating | 0.18 | 0.12 | 0.33 | 0.20 |
| S3-s | Operating | S3-s Operating | 0.18 | 0.12 | 0.33 | 0.20 |
| S4 | Operating | S4 Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S4-s | Operating | S4-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S5 | Operating | S5 Operating | 0.18 | 0.12 | 0.33 | 0.20 |
| S5-s | Operating | S5-s Operating | 0.18 | 0.12 | 0.33 | 0.20 |

**URS**

PROJECT: **Double Cell - Four Web Box - 64.125' Wide (Mainline - Case III-A)** CALCS BY: PT DATE: 10/6/09

DESCRIPTION: **STRIPED LANES - Transverse Analysis - Cline Avenue** CHECKED BY: DATE:

**Area of Steel Requirements**



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.14 | 0.10 | 0.29 | 0.15 |
| HL-93 | Operating | HL-93 Operating | 0.13 | 0.10 | 0.22 | 0.15 |
| HL-93-s | Operating | HL-93-s Operating | 0.13 | 0.10 | 0.22 | 0.15 |
| R1 | Operating | R1 Operating | 0.12 | 0.10 | 0.26 | 0.15 |
| R1-s | Operating | R1-s Operating | 0.12 | 0.10 | 0.26 | 0.15 |
| R2 | Operating | R2 Operating | 0.12 | 0.10 | 0.24 | 0.15 |
| R2-s | Operating | R2-s Operating | 0.12 | 0.10 | 0.24 | 0.15 |
| R3 | Operating | R3 Operating | 0.13 | 0.10 | 0.27 | 0.15 |
| R3-s | Operating | R3-s Operating | 0.13 | 0.10 | 0.27 | 0.15 |
| R4 | Operating | R4 Operating | 0.14 | 0.10 | 0.27 | 0.15 |
| R4-s | Operating | R4-s Operating | 0.14 | 0.10 | 0.27 | 0.15 |
| R5 | Operating | R5 Operating | 0.14 | 0.10 | 0.29 | 0.15 |
| R5-s | Operating | R5-s Operating | 0.14 | 0.10 | 0.29 | 0.15 |
| S1 | Operating | S1 Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S1-s | Operating | S1-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S2 | Operating | S2 Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S2-s | Operating | S2-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S3 | Operating | S3 Operating | 0.19 | 0.10 | 0.40 | 0.15 |
| S3-s | Operating | S3-s Operating | 0.19 | 0.10 | 0.40 | 0.15 |
| S4 | Operating | S4 Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S4-s | Operating | S4-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S5 | Operating | S5 Operating | 0.19 | 0.10 | 0.39 | 0.15 |
| S5-s | Operating | S5-s Operating | 0.19 | 0.10 | 0.39 | 0.15 |

**URS**

PROJECT: **Double Cell -Four Web Box - 71.105' Wide (Mainline - Case III-B)** CALCS BY: PT DATE: 10/6/09

DESCRIPTION: **Striped Lanes - Transverse Analysis - Cline Avenue** CHECKED BY: DATE:

**Area of Steel Requirements**

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.18 | 0.09 | 0.32 | 0.14 |
| HL-93 | Operating | HL-93 Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| R1 | Operating | R1 Operating | 0.17 | 0.09 | 0.30 | 0.14 |
| R1-s | Operating | R1-s Operating | 0.17 | 0.09 | 0.30 | 0.14 |
| R2 | Operating | R2 Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| R3 | Operating | R3 Operating | 0.15 | 0.09 | 0.27 | 0.14 |
| R3-s | Operating | R3-s Operating | 0.15 | 0.09 | 0.27 | 0.14 |
| R4 | Operating | R4 Operating | 0.16 | 0.09 | 0.29 | 0.14 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.09 | 0.29 | 0.14 |
| R5 | Operating | R5 Operating | 0.17 | 0.09 | 0.31 | 0.14 |
| R5-s | Operating | R5-s Operating | 0.17 | 0.09 | 0.31 | 0.14 |
| S1 | Operating | S1 Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S1-s | Operating | S1-s Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S2 | Operating | S2 Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S2-s | Operating | S2-s Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S3 | Operating | S3 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| S3-s | Operating | S3-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| S4 | Operating | S4 Operating | 0.18 | 0.09 | 0.33 | 0.14 |
| S4-s | Operating | S4-s Operating | 0.18 | 0.09 | 0.33 | 0.14 |
| S5 | Operating | S5 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| S5-s | Operating | S5-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |

**URS**

PROJECT: **Triple Cell- Five Web Box, 87.34' Wide ( Case IV-A)**
DESCRIPTION: **Striped Lanes - Transverse Analysis - Cline Avenue**
**Area of Steel Requirements**

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

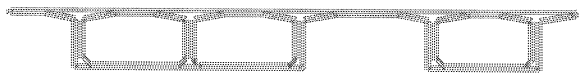
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.28 | 0.12 | 0.52 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.24 | 0.12 | 0.44 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.24 | 0.12 | 0.44 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R3 | Operating | R3 Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R4 | Operating | R4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1 | Operating | S1 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S2 | Operating | S2 Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S5 | Operating | S5 Operating | 0.35 | 0.12 | 0.64 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.35 | 0.12 | 0.64 | 0.19 |

**URS**

PROJECT: **Triple Cell- Five Web Box, 87.34' Wide ( Case IV-B)**
DESCRIPTION: **Striped Lanes - Transverse Analysis - Cline Avenue**
**Area of Steel Requirements**

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.21 | 0.12 | 0.37 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.18 | 0.12 | 0.31 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.18 | 0.12 | 0.31 | 0.19 |
| R1 | Operating | R1 Operating | 0.20 | 0.12 | 0.35 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.20 | 0.12 | 0.35 | 0.19 |
| R2 | Operating | R2 Operating | 0.19 | 0.12 | 0.33 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.19 | 0.12 | 0.33 | 0.19 |
| R3 | Operating | R3 Operating | 0.21 | 0.12 | 0.38 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.12 | 0.38 | 0.19 |
| R4 | Operating | R4 Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| R5 | Operating | R5 Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| S1 | Operating | S1 Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S2 | Operating | S2 Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S3 | Operating | S3 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S4 | Operating | S4 Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S5 | Operating | S5 Operating | 0.28 | 0.12 | 0.50 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.28 | 0.12 | 0.50 | 0.19 |

B.3/54

URS

PROJECT: **Single Cell - Two Web Box 28.34' Wide (Ramps - Case V-A)**
DESCRIPTION: **Superstructure - Transverse Analysis - Cline Avenue**
**Area of Steel Requirements**

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.03 | 0.04 | 0.10 | 0.04 |
| HL-93 | Operating | HL-93 Operating | 0.03 | 0.04 | 0.07 | 0.04 |
| HL-93-s | Operating | HL-93-s Operating | 0.03 | 0.04 | 0.07 | 0.04 |
| R1 | Operating | R1 Operating | 0.03 | 0.04 | 0.08 | 0.04 |
| R1-s | Operating | R1-s Operating | 0.03 | 0.04 | 0.08 | 0.04 |
| R2 | Operating | R2 Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R2-s | Operating | R2-s Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R3 | Operating | R3 Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R3-s | Operating | R3-s Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R4 | Operating | R4 Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| R4-s | Operating | R4-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| R5 | Operating | R5 Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| R5-s | Operating | R5-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S1 | Operating | S1 Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S1-s | Operating | S1-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S2 | Operating | S2 Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S2-s | Operating | S2-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S3 | Operating | S3 Operating | 0.03 | 0.04 | 0.10 | 0.04 |
| S3-s | Operating | S3-s Operating | 0.03 | 0.04 | 0.10 | 0.04 |
| S4 | Operating | S4 Operating | 0.04 | 0.04 | 0.05 | 0.04 |
| S4-s | Operating | S4-s Operating | 0.04 | 0.04 | 0.05 | 0.04 |
| S5 | Operating | S5 Operating | 0.03 | 0.04 | 0.05 | 0.04 |
| S5-s | Operating | S5-s Operating | 0.03 | 0.04 | 0.05 | 0.04 |

**URS**

PROJECT: **Single Cell - Two Web Box - 41.0' Wide (Ramps - Case V-B)**
DESCRIPTION: **Striped Lanes - Transverse Analysis - Cline Avenue**
**Area of Steel Requirements**

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

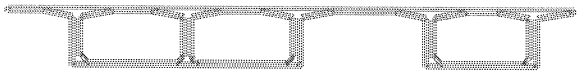
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.12 | 0.03 | 0.36 | 0.02 |
| HL-93 | Operating | HL-93 Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| HL-93-s | Operating | HL-93-s Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| R1 | Operating | R1 Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R1-s | Operating | R1-s Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R2 | Operating | R2 Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R2-s | Operating | R2-s Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R3 | Operating | R3 Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R4 | Operating | R4 Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R5 | Operating | R5 Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| R5-s | Operating | R5-s Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| S1 | Operating | S1 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S1-s | Operating | S1-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2 | Operating | S2 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2-s | Operating | S2-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S3 | Operating | S3 Operating | 0.13 | 0.03 | 0.37 | 0.02 |
| S3-s | Operating | S3-s Operating | 0.13 | 0.03 | 0.37 | 0.02 |
| S4 | Operating | S4 Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| S4-s | Operating | S4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| S5 | Operating | S5 Operating | 0.07 | 0.03 | 0.23 | 0.02 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.03 | 0.23 | 0.02 |

**URS**

PROJECT: **Cline Avenue-Single Box Portion of Section IVA-( Case VC)**
DESCRIPTION: **Striped Lanes - Transverse Analysis**
**Area of Steel Requirements**

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.16 | 0.03 | 0.31 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.13 | 0.03 | 0.26 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.13 | 0.03 | 0.26 | 0.07 |
| R1 | Operating | R1 Operating | 0.15 | 0.03 | 0.29 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.15 | 0.03 | 0.29 | 0.07 |
| R2 | Operating | R2 Operating | 0.14 | 0.03 | 0.28 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.14 | 0.03 | 0.28 | 0.07 |
| R3 | Operating | R3 Operating | 0.17 | 0.03 | 0.33 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.17 | 0.03 | 0.33 | 0.07 |
| R4 | Operating | R4 Operating | 0.17 | 0.03 | 0.32 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.17 | 0.03 | 0.32 | 0.07 |
| R5 | Operating | R5 Operating | 0.18 | 0.03 | 0.34 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.18 | 0.03 | 0.34 | 0.07 |
| S1 | Operating | S1 Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S2 | Operating | S2 Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S3 | Operating | S3 Operating | 0.25 | 0.03 | 0.48 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.25 | 0.03 | 0.48 | 0.07 |
| S4 | Operating | S4 Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S5 | Operating | S5 Operating | 0.25 | 0.03 | 0.48 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.25 | 0.03 | 0.48 | 0.07 |

**URS**

PROJECT: **Cline Avenue-Triple Cell - 6 Web Box, 111.33' Wide (Case I-A)** CALCS BY: PT DATE: 10/6/09

DESCRIPTION: **Superstructure - Transverse Analysis** CHECKED BY: DATE:

**Area of Steel Requirements**

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.25 | 0.10 | 0.46 | 0.16 |
| HL-93 | Operating | HL-93 Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| HL-93-s | Operating | HL-93-s Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| R1 | Operating | R1 Operating | 0.24 | 0.10 | 0.43 | 0.16 |
| R1-s | Operating | R1-s Operating | 0.24 | 0.10 | 0.43 | 0.16 |
| R2 | Operating | R2 Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R2-s | Operating | R2-s Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R3 | Operating | R3 Operating | 0.21 | 0.10 | 0.38 | 0.16 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.10 | 0.38 | 0.16 |
| R4 | Operating | R4 Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R4-s | Operating | R4-s Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R5 | Operating | R5 Operating | 0.24 | 0.10 | 0.42 | 0.16 |
| R5-s | Operating | R5-s Operating | 0.24 | 0.10 | 0.42 | 0.16 |
| S1 | Operating | S1 Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S1-s | Operating | S1-s Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S2 | Operating | S2 Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S2-s | Operating | S2-s Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S3 | Operating | S3 Operating | 0.28 | 0.10 | 0.50 | 0.16 |
| S3-s | Operating | S3-s Operating | 0.28 | 0.10 | 0.50 | 0.16 |
| S4 | Operating | S4 Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| S4-s | Operating | S4-s Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| S5 | Operating | S5 Operating | 0.25 | 0.10 | 0.46 | 0.16 |
| S5-s | Operating | S5-s Operating | 0.25 | 0.10 | 0.46 | 0.16 |

83/58

URS

PROJECT: Double Cell - Three Web Box, 48'-4" Wide ( Ramps - Case II-A

DESCRIPTION: Superstructure - Transverse Analysis Cline Avenue

Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09

CHECKED BY: DATE:

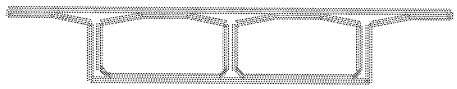
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.09 | 0.05 | 0.25 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R1 | Operating | R1 Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R2 | Operating | R2 Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R3 | Operating | R3 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| R4 | Operating | R4 Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R5 | Operating | R5 Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| S1 | Operating | S1 Operating | 0.08 | 0.05 | 0.21 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.08 | 0.05 | 0.21 | 0.07 |
| S2 | Operating | S2 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S3 | Operating | S3 Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S4 | Operating | S4 Operating | 0.08 | 0.05 | 0.16 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.08 | 0.05 | 0.16 | 0.07 |
| S5 | Operating | S5 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |

URS

PROJECT: Double Cell - Three Web Box - 55.625' Wide (Mainline - Case II-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

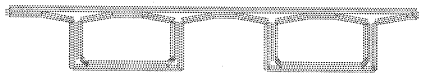
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.29 | 0.12 | 0.55 | 0.20 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.47 | 0.20 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.47 | 0.20 |
| R1 | Operating | R1 Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R1-s | Operating | R1-s Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R3 | Operating | R3 Operating | 0.26 | 0.12 | 0.48 | 0.20 |
| R3-s | Operating | R3-s Operating | 0.26 | 0.12 | 0.48 | 0.20 |
| R4 | Operating | R4 Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R4-s | Operating | R4-s Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| S1 | Operating | S1 Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S1-s | Operating | S1-s Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S2 | Operating | S2 Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S2-s | Operating | S2-s Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.63 | 0.20 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.63 | 0.20 |
| S4 | Operating | S4 Operating | 0.28 | 0.12 | 0.50 | 0.20 |
| S4-s | Operating | S4-s Operating | 0.28 | 0.12 | 0.50 | 0.20 |
| S5 | Operating | S5 Operating | 0.32 | 0.12 | 0.60 | 0.20 |
| S5-s | Operating | S5-s Operating | 0.32 | 0.12 | 0.60 | 0.20 |

8.3/60

**URS**

PROJECT: Double Cell - Four Web Box - 64.125' Wide (Mainline - Case III-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.24 | 0.10 | 0.45 | 0.15 |
| HL-93 | Operating | HL-93 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| HL-93-s | Operating | HL-93-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R1 | Operating | R1 Operating | 0.23 | 0.10 | 0.42 | 0.15 |
| R1-s | Operating | R1-s Operating | 0.23 | 0.10 | 0.42 | 0.15 |
| R2 | Operating | R2 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R2-s | Operating | R2-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R3 | Operating | R3 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R4 | Operating | R4 Operating | 0.21 | 0.10 | 0.37 | 0.15 |
| R4-s | Operating | R4-s Operating | 0.21 | 0.10 | 0.37 | 0.15 |
| R5 | Operating | R5 Operating | 0.23 | 0.10 | 0.41 | 0.15 |
| R5-s | Operating | R5-s Operating | 0.23 | 0.10 | 0.41 | 0.15 |
| S1 | Operating | S1 Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S1-s | Operating | S1-s Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S2 | Operating | S2 Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S2-s | Operating | S2-s Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S3 | Operating | S3 Operating | 0.27 | 0.10 | 0.49 | 0.15 |
| S3-s | Operating | S3-s Operating | 0.27 | 0.10 | 0.49 | 0.15 |
| S4 | Operating | S4 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| S4-s | Operating | S4-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| S5 | Operating | S5 Operating | 0.25 | 0.10 | 0.46 | 0.15 |
| S5-s | Operating | S5-s Operating | 0.25 | 0.10 | 0.46 | 0.15 |

8.3/01

URS

PROJECT: Double Cell -Four Web Box - 71.105' Wide (Mainline - Case III-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

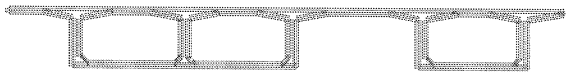
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.23 | 0.09 | 0.43 | 0.14 |
| HL-93 | Operating | HL-93 Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| HL-93-s | Operating | HL-93-s Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R1 | Operating | R1 Operating | 0.22 | 0.09 | 0.40 | 0.14 |
| R1-s | Operating | R1-s Operating | 0.22 | 0.09 | 0.40 | 0.14 |
| R2 | Operating | R2 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R2-s | Operating | R2-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R3 | Operating | R3 Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R3-s | Operating | R3-s Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R4 | Operating | R4 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R4-s | Operating | R4-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R5 | Operating | R5 Operating | 0.22 | 0.09 | 0.39 | 0.14 |
| R5-s | Operating | R5-s Operating | 0.22 | 0.09 | 0.39 | 0.14 |
| S1 | Operating | S1 Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S1-s | Operating | S1-s Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S2 | Operating | S2 Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S2-s | Operating | S2-s Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S3 | Operating | S3 Operating | 0.25 | 0.09 | 0.47 | 0.14 |
| S3-s | Operating | S3-s Operating | 0.25 | 0.09 | 0.47 | 0.14 |
| S4 | Operating | S4 Operating | 0.20 | 0.09 | 0.37 | 0.14 |
| S4-s | Operating | S4-s Operating | 0.20 | 0.09 | 0.37 | 0.14 |
| S5 | Operating | S5 Operating | 0.23 | 0.09 | 0.44 | 0.14 |
| S5-s | Operating | S5-s Operating | 0.23 | 0.09 | 0.44 | 0.14 |

8.3/62

**URS**

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

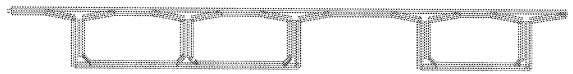
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.28 | 0.12 | 0.53 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R3 | Operating | R3 Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R4 | Operating | R4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1 | Operating | S1 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S2 | Operating | S2 Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S5 | Operating | S5 Operating | 0.35 | 0.12 | 0.64 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.35 | 0.12 | 0.64 | 0.19 |

8.3/63

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

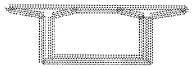
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.29 | 0.12 | 0.53 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.50 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.50 | 0.19 |
| R2 | Operating | R2 Operating | 0.25 | 0.12 | 0.46 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.25 | 0.12 | 0.46 | 0.19 |
| R3 | Operating | R3 Operating | 0.25 | 0.12 | 0.47 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.25 | 0.12 | 0.47 | 0.19 |
| R4 | Operating | R4 Operating | 0.26 | 0.12 | 0.46 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.26 | 0.12 | 0.46 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.50 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.50 | 0.19 |
| S1 | Operating | S1 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S2 | Operating | S2 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S3 | Operating | S3 Operating | 0.33 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.33 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S5 | Operating | S5 Operating | 0.32 | 0.12 | 0.59 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.32 | 0.12 | 0.59 | 0.19 |

8.3/64

**URS**

PROJECT: Single Cell - Two Web Box 28.34' Wide (Ramps - Case V-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.06 | 0.04 | 0.12 | 0.04 |
| HL-93 | Operating | HL-93 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| HL-93-s | Operating | HL-93-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| R1 | Operating | R1 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R1-s | Operating | R1-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R2 | Operating | R2 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R2-s | Operating | R2-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R3 | Operating | R3 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R3-s | Operating | R3-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R4 | Operating | R4 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R4-s | Operating | R4-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R5 | Operating | R5 Operating | 0.06 | 0.04 | 0.11 | 0.04 |
| R5-s | Operating | R5-s Operating | 0.06 | 0.04 | 0.11 | 0.04 |
| S1 | Operating | S1 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S1-s | Operating | S1-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S2 | Operating | S2 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S2-s | Operating | S2-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S3 | Operating | S3 Operating | 0.06 | 0.04 | 0.13 | 0.04 |
| S3-s | Operating | S3-s Operating | 0.06 | 0.04 | 0.13 | 0.04 |
| S4 | Operating | S4 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S4-s | Operating | S4-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S5 | Operating | S5 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S5-s | Operating | S5-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |

8.3/85

**URS**

PROJECT: Single Cell - Two Web Box - 41.0' Wide (Ramps - Case V-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

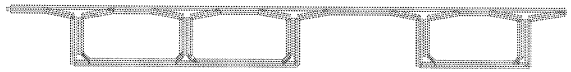
| Section | Inventory / Operating | Combined Name | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| | | | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.12 | 0.03 | 0.36 | 0.02 |
| HL-93 | Operating | HL-93 Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| HL-93-s | Operating | HL-93-s Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| R1 | Operating | R1 Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R1-s | Operating | R1-s Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R2 | Operating | R2 Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R2-s | Operating | R2-s Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R3 | Operating | R3 Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R4 | Operating | R4 Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R5 | Operating | R5 Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| R5-s | Operating | R5-s Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| S1 | Operating | S1 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S1-s | Operating | S1-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2 | Operating | S2 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2-s | Operating | S2-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S3 | Operating | S3 Operating | 0.12 | 0.03 | 0.33 | 0.02 |
| S3-s | Operating | S3-s Operating | 0.12 | 0.03 | 0.33 | 0.02 |
| S4 | Operating | S4 Operating | 0.08 | 0.03 | 0.27 | 0.02 |
| S4-s | Operating | S4-s Operating | 0.08 | 0.03 | 0.27 | 0.02 |
| S5 | Operating | S5 Operating | 0.07 | 0.03 | 0.08 | 0.02 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.03 | 0.08 | 0.02 |

8.3/66

**URS**

PROJECT: Cline Avenue-Single Box Portion of Section IVA-( Case VC)
DESCRIPTION: Superstructure - Transverse Analysis
Area of Steel Requirements

CALCS BY: PT DATE: 10/6/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.20 | 0.03 | 0.40 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.16 | 0.03 | 0.32 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.16 | 0.03 | 0.32 | 0.07 |
| R1 | Operating | R1 Operating | 0.18 | 0.03 | 0.37 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.18 | 0.03 | 0.37 | 0.07 |
| R2 | Operating | R2 Operating | 0.17 | 0.03 | 0.35 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.17 | 0.03 | 0.35 | 0.07 |
| R3 | Operating | R3 Operating | 0.20 | 0.03 | 0.40 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.20 | 0.03 | 0.40 | 0.07 |
| R4 | Operating | R4 Operating | 0.19 | 0.03 | 0.38 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.19 | 0.03 | 0.38 | 0.07 |
| R5 | Operating | R5 Operating | 0.20 | 0.03 | 0.41 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.20 | 0.03 | 0.41 | 0.07 |
| S1 | Operating | S1 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S2 | Operating | S2 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S3 | Operating | S3 Operating | 0.28 | 0.03 | 0.54 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.28 | 0.03 | 0.54 | 0.07 |
| S4 | Operating | S4 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S5 | Operating | S5 Operating | 0.28 | 0.03 | 0.55 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.28 | 0.03 | 0.55 | 0.07 |

83/67

# 8.4 Revised Transverse Analysis Based on Revised Effective Span Length

## 8.4 Revised Transverse Analysis Based on Revised Effective Span Length

## GEOMETRY.

There is a large variation on the bridge cross section geometry throughout the length of the bridge. Such variations have been considered in the longitudinal RM model. However, for the transverse analysis only 5 cases have been considered.

Effective Length RUB

**Case I**

168'

**case II**

case IIA - Ramp. 102'

case IIB - Mainline. 183'

**case III**

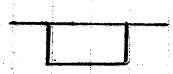
case IIIA constant width 182'

Case IIIB maximum width 170'

**case IV**

183'

**case V**



Case VA - Ramp - minimum width 122'

Case VB - Ramp - maximum width 113'

case VC - Single Box of Case IV 183'

A detailed description has been included later.

URS

PROJECT: Cline Avenue | CALCS BY: RJB | DATE: Sep-09
DESCRIPTION: Effective Length | CHECKED BY: PT | DATE: 9/9
FILE: V:\Projects\Cline Avenue\Load Rating Analysis\Transverse Analysis\[Cline_Spans.xls]Sheet1

0.58L (Int Span)
0.75L (End Span)

East Bound

| Segment | Case | Span | | Span Length | | | | Eff. Span Length |
|---|---|---|---|---|---|---|---|---|
| 1 | I A | 1 | E | 102.2083 | | | | 76.7 |
| 1 | I A | 2 | I | 190.2500 | | | | 110.3 |
| 1 | I A | 3 | I | 207.0000 | | | | 120.1 |
| 1 | I A | 4 | I | 265.7500 | | | | 154.1 |
| 1 | I A | 5 | I | 265.7500 | | | | 154.1 |
| 1 & 2 | I A & II B | 6 | E | 265.7500 | 224.2500 | 41.5000 | 265.7500 | 168.2 |
| 2 | II B | 7 | I | 257.9479 | | | | 149.6 |
| 2 | II B | 8 | I | 284.3958 | | | | 164.9 |
| 2 | II B | 9 | I | 292.1979 | | | | 169.5 |
| 2 & 3 | II B | 10 | E | 292.1979 | 242.8854 | 49.3125 | 292.1979 | 182.2 |
| 3 | II B | 11 | I | 292.1979 | | | | 169.5 |
| 3 | II B | 12 | I | 315.6042 | | | | 183.1 |
| 3 | III A | 13 | I | 290.6042 | | | | 168.6 |
| 3 & 4 | III A & III B | 14 | E | 245.6042 | 41.5104 | 204.0938 | 245.6042 | 153.1 |
| 4 | III B & IV A | 15 | I | 215.0000 | Section Change | | | 124.7 |
| 4 | IV A | 16 | I | 215.0000 | | | | 124.7 |
| 4 | II B | 17 | I | 215.0000 | | | | 124.7 |
| 4 & 5 | II B | 18 | E | 195.0000 | 161.2917 | 33.7083 | 195.0000 | 121.0 |
| 5 | II B | 19 | I | 195.0000 | | | | 113.1 |
| 5 | II B | 20 | I | 195.0000 | | | | 113.1 |
| 5 | II B | 21 | I | 195.0000 | | | | 113.1 |
| 5 | II B | 22 | I | 202.8021 | | | | 117.6 |
| 5 & 6 | II B | 23 | E | 214.1979 | 180.4896 | 33.7083 | 214.1979 | 135.4 |
| 6 | II B | 24 | I | 222.0000 | | | | 128.8 |
| 6 | IV A | 25 | I | 222.0000 | | | | 128.8 |
| 6 | IV A | 26 | I | 222.0000 | | | | 128.8 |
| 6 | IV A | 27 | E | 178.0000 | | | | 133.5 |

0.75 (L hinge)

8 of 3

URS

PROJECT: Cline Avenue
DESCRIPTION: Effective Length
FILE: V:\Projects\Cline Avenue\Load Rating Analysis\Transverse Analysis\[Cline_Spans.xls]Sheet1

CALCS BY: RJB DATE: Sep-09
CHECKED BY: RT DATE: 9/9

West Bound

| Segment | Case | Span | | Span Length | | | | Eff. Span Length |
|---|---|---|---|---|---|---|---|---|
| 1 | I A | 1 | E | 102.2083 | | | | 76.7 |
| 1 | I A | 2 | I | 190.2500 | | | | 110.3 |
| 1 | I A | 3 | I | 207.0000 | | | | 120.1 |
| 1 | I A | 4 | I | 265.7500 | | | | 154.1 |
| 1 | I A | 5 | I | 265.7500 | | | | 154.1 |
| 1 & 2 | I A & II B | 6 | E | 265.7500 | 224.2500 | 41.5000 | 265.7500 | 168.2 |
| 2 | II B | 7 | I | 257.9479 | | | | 149.6 |
| 2 | II B | 8 | I | 284.3958 | | | | 164.9 |
| 2 | III A | 9 | I | 292.1979 | | | | 169.5 |
| 2 & 3 | III A | 10 | | 292.1979 | 242.8854 | 49.3125 | 292.1979 | 182.2 |
| 3 | III B & IV A | 11 | | 292.1979 | | | | 169.5 |
| 3 | IV A | 12 | I | 315.6042 | | | | 183.1 |
| 3 | IV A & II B | 13 | I | 290.6042 | | | | 168.6 |
| 3 & 4 | II B | 14 | E | 245.6042 | 41.5104 | 204.0938 | 245.6042 | 153.1 |
| 4 | II B | 15 | I | 215.0000 | | | | 124.7 |
| 4 | II B | 16 | I | 215.0000 | | | | 124.7 |
| 4 | II B | 17 | I | 215.0000 | | | | 124.7 |
| 4 & 5 | II B | 18 | E | 195.0000 | 161.2917 | 33.7083 | 195.0000 | 121.0 |
| 5 | II B | 19 | I | 190.0000 | | | | 110.2 |
| 5 | II B | 20 | I | 172.5000 | | | | 100.1 |
| 5 | II B | 21 | I | 172.5000 | | | | 100.1 |
| 5 | II B | 22 | I | 200.0000 | | | | 116.0 |
| 5 & 6 | II B | 23 | E | 200.0000 | 166.2917 | 33.7083 | 200.0000 | 124.7 |
| 6 | II B | 24 | I | 195.0000 | | | | 113.1 |
| 6 | II B | 25 | I | 195.0000 | | | | 113.1 |
| 6 | II B | 26 | I | 183.0000 | | | | 106.1 |
| 6 | II B & IV A | 27 | I | 198.0000 | | | | 114.8 |
| 6 | IV A | 28 | E | 140.0000 | | | | 105.0 |

8.4/4

URS

PROJECT: Cline Avenue
DESCRIPTION: Effective Length
FILE: V:\Projects\Cline Avenue\Load Rating Analysis\Transverse Analysis\[Cline_Spans.xls]Sheet1

CALCS BY: RJB DATE: Sep-09
CHECKED BY: PT DATE: 9/9

Ramps

| | Case | Span | | Span Length | Eff. Span Length |
|---|---|---|---|---|---|
| A | V A | 1 | E | 98.6042 | 74.0 |
| A | V A | 2 | I | 210.6042 | 122.2 |
| A | V A | 3 | I | 195.0000 | 113.1 |
| A | V A | 4 | I | 195.0000 | 113.1 |
| A | II A | 5 | I | 175.0000 | 101.5 |
| A | II A | 6 | I | 175.0000 | 101.5 |
| A | II A | 7 | E | 108.2500 | 81.2 |
| B | V A | 1 | E | 100.0000 | 75.0 |
| B | V A | 2 | I | 197.0000 | 114.3 |
| B | IV A (VC) | 3 | E | 97.9531 | 73.5 |
| C | V A | 1 | E | 126.1042 | 94.6 |
| C | V A | 2 | I | 180.0000 | 104.4 |
| C | V A | 3 | I | 180.0000 | 104.4 |
| C | V A | 4 | I | 180.0000 | 104.4 |
| C | V A | 5 | I | 180.0000 | 104.4 |
| C | V A | 6 | I | 160.0000 | 92.8 |
| C | V A | 7 | I | 160.0000 | 92.8 |
| C | V A | 8 | I | 120.0000 | 69.6 |
| C | V A | 9 | I | 120.0000 | 69.6 |
| C | V A | 10 | E | 72.0000 | 54.0 |
| D | V A | 1 | E | 86.0000 | 64.5 |
| D | V A | 2 | I | 160.0000 | 92.8 |
| D | V A | 3 | I | 195.0000 | 113.1 |
| D | IV A (VC) | 4 | E | 166.3333 | 124.7 |

8.4/6

URS

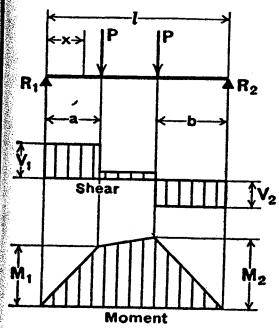
PROJECT: Cline Avenue CALCS BY: PT DATE:
DESCRIPTION: Transverse Section CHECKED BY: DATE:
FILE: V:\Projects\Cline Avenue\Load Rating Analysis\Transverse Analysis\Spreadsheet_AASHTO_lanes_5.75.44\[Props&

| UNIT | Transverse Section ID | Rating Node | RM Segment |
|---|---|---|---|
| Segment 1 - Gdr 1 | IA | 1-173 | 1001-1172 |
| Segment 1 - Gdr 2 | IA | 1-173 | 2001-2172 |
| Segment 1 - Gdr 3 | IA | 1-173 | 3001-3172 |
| Segment 2 - EBL | IIB | 1-151 | 1174-1323 |
| Segment 2 - WBL | IIB | 1-80 | 2174-2252 |
| | IIIA | 80-151 | 2253-2323 |
| Segment 3 - EBL | IIB | 1-72 | 1325-1395 |
| | IIIA | 72-117 | 1396-1440 |
| Segment 3 - WBL | IIIA | 1-8 | 2325-2331 |
| | IIIB | 8-36 | 2332-2359 |
| | IVA | 36-76 | 2360-2399 |
| | IIB | 76-117 | 2400-2440 |
| Segment 4 - EBL | IIIA | 1-11 | 1442-1451 |
| | IIIB | 11-53 | 1452-1493 |
| | IVA | 53-87 | 1494-1527 |
| | IIB | 87-138 | 1528-1578 |
| Segment 4 - WBL | IIB | 1-138 | 2442-2578 |
| Segment 5 - EBL | IIB | 1-138 | 1580-1716 |
| Segment 5 - WBL | IIB | 1-128 | 2580-2706 |
| Segment 6 - EBL | IIB | 1-36 | 1718-1752 |
| | IVA | 36-122 | 1753-1838 |
| Segment 6 - WBL | IIB | 1-100 | 2708-2806 |
| | IVA | 100-133 | 2807-2839 |
| Ramp A - Segment 2 | IIIA | 1-72 | 4001-4071 |
| Ramp A - Segment 3 | IIIA | 1-8 | 4073-4079 |
| | IIIB | 8-36 | 4080-4107 |
| | IVA (VC) | 36-74 | 4108-4147 |
| | VC | 74-83 | 4148-4154 |
| Ramp A | VA | 1-57 | 4156-4211 |
| | VB | 57-97 | 4212-4251 |
| | IIA | 97-155 | 4252-4309 |
| Ramp B | VA | 1-48 | 4501-4547 |
| Ramp B - Segment 6 | IVA (VC) | 1-35 | 4548-4581 |
| Ramp C - Segment 3 | IIIA | 1-46 | 5001-5045 |
| Ramp C - Segment 4 | IIIA | 1-11 | 5047-5056 |
| | IIIB | 11-53 | 5057-5098 |
| | IVA (VC) | 53-86 | 5099-5131 |
| | VC | 86-94 | 5132-5139 |
| Ramp C - Units 2-5 | VA | 1-100 | 5141-5239 |
| Ramp C - Units 1 6-8 | VA | 1-107 | 5241-5346 |
| Ramp D | VA | 1-81 | 5501-5580 |
| Ramp D - Segment 6 | IVA (VC) | 1-100 | 5582-5680 |

# BEAM DIAGRAMS AND FORMULAS
## For various static loading conditions

For meaning of symbols, see page 3-127

### 10. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS UNSYMMETRICALLY PLACED




$R_1 = V_1$ (max. when $a < b$) . . . . $= \frac{P}{l}(l - a + b)$

$R_2 = V_2$ (max. when $a > b$) . . . . $= \frac{P}{l}(l - b + a)$

$V_x$ (when $x > a$ and $< (l - b)$) . . $= \frac{P}{l}(b - a)$

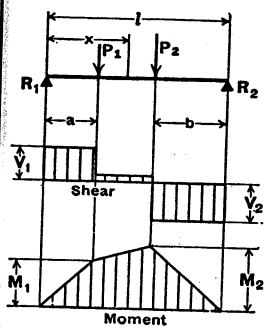
$M_1$ (max. when $a > b$) . . . . $= R_1 a$

$M_2$ (max. when $a < b$) . . . . $= R_2 b$

$M_x$ (when $x < a$) . . . . . $= R_1 x$

$M_x$ (when $x > a$ and $< (l - b)$) . . $= R_1 x - P(x - a)$

### 11. SIMPLE BEAM—TWO UNEQUAL CONCENTRATED LOADS UNSYMMETRICALLY PLACED




$R_1 = V_1$ . . . . . $= \frac{P_1(l - a) + P_2 b}{l}$

$R_2 = V_2$ . . . . . $= \frac{P_1 a + P_2(l - b)}{l}$

$V_x$ (when $x > a$ and $< (l - b)$) . . $= R_1 - P_1$

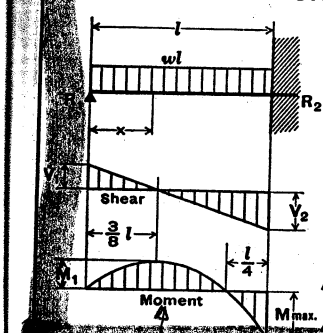
$M_1$ (max. when $R_1 < P_1$) . . . $= R_1 a$

$M_2$ (max. when $R_2 < P_2$) . . . $= R_2 b$

$M_x$ (when $x < a$) . . . . . $= R_1 x$

$M_x$ (when $x > a$ and $< (l - b)$) . . $= R_1 x - P_1(x - a)$

### 12. BEAM FIXED AT ONE END, SUPPORTED AT OTHER UNIFORMLY DISTRIBUTED LOAD




Total Equiv. Uniform Load . . . . . $= wl$

$R_1 = V_1$ . . . . . $= \frac{3wl}{8}$

$R_2 = V_2$ max. . . . . $= \frac{5wl}{8}$

$V_x$ . . . . . $= R_1 - wx$

M max. . . . . $= \frac{wl^2}{8}$

$M_1$ (at $x = \frac{3}{8}l$) . . . . . $= \frac{9}{128}wl^2$

$M_x$ . . . . . $= R_1 x - \frac{wx^2}{2}$

$\Delta$max. (at $x = \frac{l}{16}(1 + \sqrt{33}) = .4215l$) . $= \frac{wl^4}{185EI}$

$= \frac{wx}{48EI}(l^3 - 3lx^2 + 2x^3)$

0.75L



MS AND FORMULAS
ir 'ading conditions
yi... s, see page 3-127

ITRATED LOAD AT CENTER

rm Load . . . . . = 2P

. . . . . = $\frac{P}{2}$

of load) . . . . . = $\frac{Pl}{4}$

$< \frac{l}{2}$ ) . . . . . = $\frac{Px}{2}$

of load) . . . . . = $\frac{Pl^3}{48EI}$

$< \frac{l}{2}$ ) . . . . . = $\frac{Px}{48EI}(3l^2 - 4x^2)$

NTRATED LOAD AT ANY POINT

m Load . . . . . = $\frac{8\,Pab}{l^2}$

en $a < b$) . . . . = $\frac{Pb}{l}$

en $a > b$) . . . . = $\frac{Pa}{l}$

of load) . . . . = $\frac{Pab}{l}$

$x < a$ ) . . . . = $\frac{Pbx}{l}$

$a(a + 2b)$ when $a > b$) = $\frac{Pab(a + 2b)\sqrt{3a(a + 2b)}}{27\,EI\,l}$

of load) . . . . = $\frac{Pa^2b^2}{3EI\,l}$

$x < a$ ) . . . . = $\frac{Pbx}{6EI\,l}(l^2 - b^2 - x^2)$

QUAL CONCENTRATED LOADS
CALLY PLACED

rm Load . . . . . = $\frac{8\,Pa}{l}$

. . . . . = P

loads) . . . . . = Pa

$< a$) . . . . . = Px

r) . . . . . = $\frac{Pa}{24EI}(3l^2 - 4a^2)$

$< a$) . . . . . = $\frac{Px}{6EI}(3la - 3a^2 - x^2)$

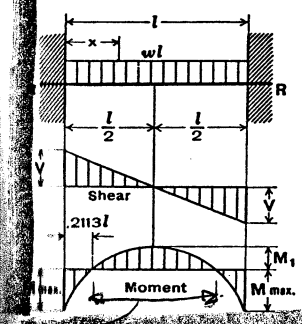
$> a$ and $< (l - a)$) . . = $\frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

8.4/8

# BEAM DIAGRAMS AND FORMULAS
## For various static loading conditions

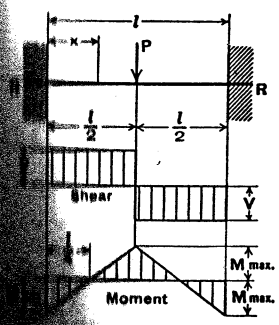
For meaning of symbols, see page 3-127

### 15. BEAM FIXED AT BOTH ENDS—UNIFORMLY DISTRIBUTED LOADS



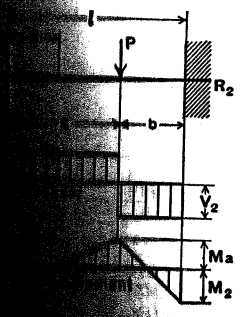

| | |
|---|---|
| Total Equiv. Uniform Load | $= \frac{2wl}{3}$ |
| R = V | $= \frac{wl}{2}$ |
| $V_x$ | $= w\left(\frac{l}{2} - x\right)$ |
| M max. (at ends) | $= \frac{wl^2}{12}$ |
| $M_1$ (at center) | $= \frac{wl^2}{24}$ |
| $M_x$ | $= \frac{w}{12}(6lx - l^2 - 6x^2)$ |
| Δmax. (at center) | $= \frac{wl^4}{384EI}$ |
| $\Delta_x$ | $= \frac{wx^2}{24EI}(l - x)^2$ |

### 16. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT CENTER




| | |
|---|---|
| Total Equiv. Uniform Load | = P |
| R = V | $= \frac{P}{2}$ |
| M max. (at center and ends) | $= \frac{Pl}{8}$ |
| $M_x$ (when $x < \frac{l}{2}$) | $= \frac{P}{8}(4x - l)$ |
| Δmax. (at center) | $= \frac{Pl^3}{192EI}$ |
| $\Delta_x$ (when $x < \frac{l}{2}$) | $= \frac{Px^2}{48EI}(3l - 4x)$ |

### 17. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT ANY POINT

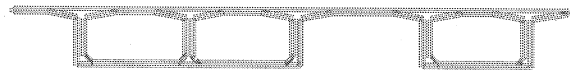



| | |
|---|---|
| $R_1 = V_1$ (max. when a < b) | $= \frac{Pb^2}{l^3}(3a + b)$ |
| $R_2 = V_2$ (max. when a > b) | $= \frac{Pa^2}{l^3}(a + 3b)$ |
| $M_1$ (max. when a < b) | $= \frac{Pab^2}{l^2}$ |
| $M_2$ (max. when a > b) | $= \frac{Pa^2b}{l^2}$ |
| Ma (at point of load) | $= \frac{2Pa^2b^2}{l^3}$ |
| $M_x$ (when x < a) | $= R_1x - \frac{Pab^2}{l^2}$ |
| Δmax. (when a > b at $x = \frac{2al}{3a + b}$) | $= \frac{2Pa^3b^2}{3EI(3a + b)^2}$ |
| Δa (at point of load) | $= \frac{Pa^3b^3}{3EIl^3}$ |
| $\Delta_x$ (when x < a) | $= \frac{Pb^2x^2}{6EIl^3}(3al - 3ax - bx)$ |

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



| Section | Inventory / Operating | Combined Name | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| | | | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.28 | 0.12 | 0.53 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R3 | Operating | R3 Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R4 | Operating | R4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1 | Operating | S1 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S2 | Operating | S2 Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S5 | Operating | S5 Operating | 0.35 | 0.12 | 0.64 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.35 | 0.12 | 0.64 | 0.19 |

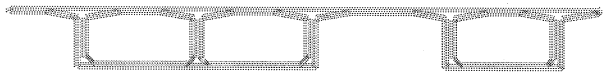
2.4/9

STRIPED

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-B)
DESCRIPTION: Striped Lanes - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/15/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.21 | 0.12 | 0.37 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.18 | 0.12 | 0.31 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.20 | 0.12 | 0.35 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.19 | 0.12 | 0.33 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.12 | 0.38 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.21 | 0.12 | 0.37 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.24 | 0.12 | 0.43 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.28 | 0.12 | 0.50 | 0.19 |

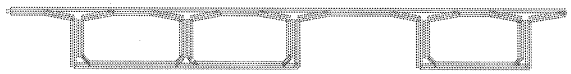
8.4/10

AASHTO

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/15/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.29 | 0.12 | 0.53 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.50 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.50 | 0.19 |
| R2 | Operating | R2 Operating | 0.25 | 0.12 | 0.46 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.25 | 0.12 | 0.46 | 0.19 |
| R3 | Operating | R3 Operating | 0.25 | 0.12 | 0.47 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.25 | 0.12 | 0.47 | 0.19 |
| R4 | Operating | R4 Operating | 0.26 | 0.12 | 0.46 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.26 | 0.12 | 0.46 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.50 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.50 | 0.19 |
| S1 | Operating | S1 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S2 | Operating | S2 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S3 | Operating | S3 Operating | 0.33 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.33 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| S5 | Operating | S5 Operating | 0.32 | 0.12 | 0.59 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.32 | 0.12 | 0.59 | 0.19 |

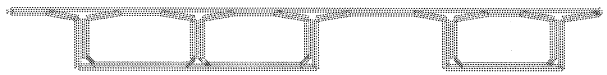
11/72

Striped

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-C)
DESCRIPTION: Striped Lanes - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/15/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

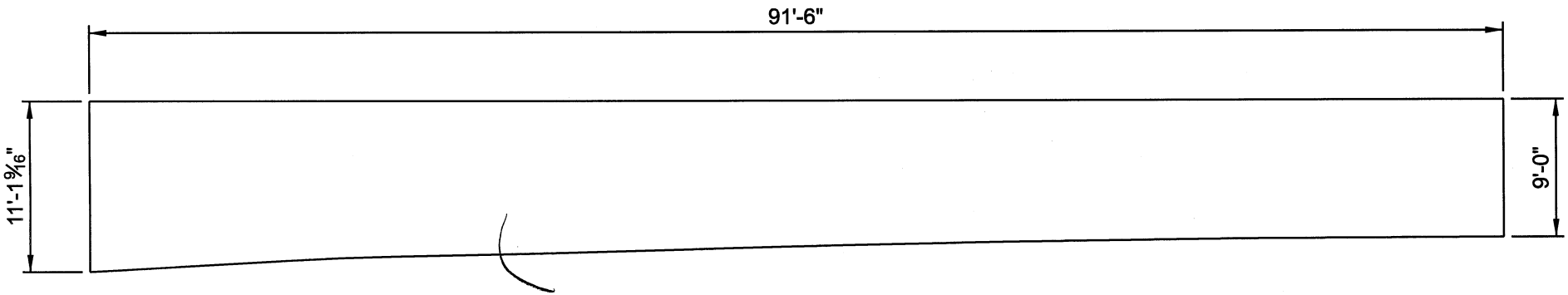
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.20 | 0.12 | 0.31 | 0.17 |
| HL-93-s | Operating | HL-93-s Operating | 0.17 | 0.12 | 0.26 | 0.17 |
| R1-s | Operating | R1-s Operating | 0.20 | 0.12 | 0.29 | 0.17 |
| R2-s | Operating | R2-s Operating | 0.19 | 0.12 | 0.28 | 0.17 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.12 | 0.32 | 0.17 |
| R4-s | Operating | R4-s Operating | 0.21 | 0.12 | 0.31 | 0.17 |
| R5-s | Operating | R5-s Operating | 0.21 | 0.12 | 0.33 | 0.17 |
| S1-s | Operating | S1-s Operating | 0.24 | 0.12 | 0.37 | 0.17 |
| S2-s | Operating | S2-s Operating | 0.24 | 0.12 | 0.37 | 0.17 |
| S3-s | Operating | S3-s Operating | 0.27 | 0.12 | 0.44 | 0.17 |
| S4-s | Operating | S4-s Operating | 0.24 | 0.12 | 0.37 | 0.17 |
| S5-s | Operating | S5-s Operating | 0.28 | 0.12 | 0.44 | 0.17 |

2.4/12

```
* code 1203 - profile 8
    5    2    3
0.0000    1.1667
1.2917    1.1667
3.7500    1.1667
7.8541    1.1667
9.0833     1.1667
```



8.4/13




$$\text{Avg Depth} = \frac{885.72}{91.5} = 9.68' = 116.2''$$

Transverse Analysis.dgn 9/15/2009 5:23:10 PM

$$\text{Brug Model Depth} = 116.2'' - \frac{9''}{2} - \frac{5.5''}{2} = \underline{109.0''}$$

$$\underline{9.0833'}$$

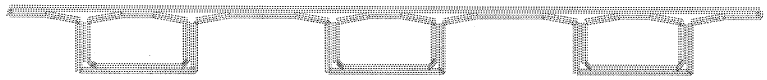
2.4/14

URS

PROJECT: Cline Avenue-Triple Cell - 6 Web Box, 111.33' Wide (Case I-A) CALCS BY: PT DATE: 9/14/09

DESCRIPTION: Superstructure - Transverse Analysis CHECKED BY: DATE:

Area of Steel Requirements



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.25 | 0.10 | 0.46 | 0.16 |
| HL-93 | Operating | HL-93 Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| R1 | Operating | R1 Operating | 0.24 | 0.10 | 0.43 | 0.16 |
| R2 | Operating | R2 Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R3 | Operating | R3 Operating | 0.21 | 0.10 | 0.38 | 0.16 |
| R4 | Operating | R4 Operating | 0.22 | 0.10 | 0.38 | 0.16 |
| R5 | Operating | R5 Operating | 0.24 | 0.10 | 0.42 | 0.16 |
| S1 | Operating | S1 Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S2 | Operating | S2 Operating | 0.23 | 0.10 | 0.41 | 0.16 |
| S3 | Operating | S3 Operating | 0.28 | 0.10 | 0.50 | 0.16 |
| S4 | Operating | S4 Operating | 0.22 | 0.10 | 0.39 | 0.16 |
| S5 | Operating | S5 Operating | 0.25 | 0.10 | 0.46 | 0.16 |

URS

PROJECT: Double Cell - Three Web Box, 48'-4" Wide ( Ramps - Case II-A)
DESCRIPTION: Superstructure - Transverse Analysis Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

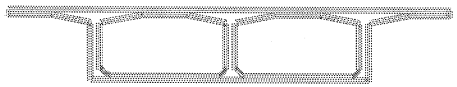
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.09 | 0.05 | 0.25 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R1 | Operating | R1 Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R2 | Operating | R2 Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.08 | 0.05 | 0.19 | 0.07 |
| R3 | Operating | R3 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| R4 | Operating | R4 Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.05 | 0.22 | 0.07 |
| R5 | Operating | R5 Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| S1 | Operating | S1 Operating | 0.08 | 0.05 | 0.21 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.08 | 0.05 | 0.21 | 0.07 |
| S2 | Operating | S2 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S3 | Operating | S3 Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S4 | Operating | S4 Operating | 0.08 | 0.05 | 0.16 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.08 | 0.05 | 0.16 | 0.07 |
| S5 | Operating | S5 Operating | 0.08 | 0.05 | 0.20 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.08 | 0.05 | 0.20 | 0.07 |

9/14/09

URS

PROJECT: Double Cell - Three Web Box - 55.625' Wide (Mainline - Case II-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.29 | 0.12 | 0.55 | 0.20 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.47 | 0.20 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.47 | 0.20 |
| R1 | Operating | R1 Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R1-s | Operating | R1-s Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R3 | Operating | R3 Operating | 0.26 | 0.12 | 0.48 | 0.20 |
| R3-s | Operating | R3-s Operating | 0.26 | 0.12 | 0.48 | 0.20 |
| R4 | Operating | R4 Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R4-s | Operating | R4-s Operating | 0.26 | 0.12 | 0.47 | 0.20 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.20 |
| S1 | Operating | S1 Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S1-s | Operating | S1-s Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S2 | Operating | S2 Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S2-s | Operating | S2-s Operating | 0.28 | 0.12 | 0.52 | 0.20 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.63 | 0.20 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.63 | 0.20 |
| S4 | Operating | S4 Operating | 0.28 | 0.12 | 0.50 | 0.20 |
| S4-s | Operating | S4-s Operating | 0.28 | 0.12 | 0.50 | 0.20 |
| S5 | Operating | S5 Operating | 0.32 | 0.12 | 0.60 | 0.20 |
| S5-s | Operating | S5-s Operating | 0.32 | 0.12 | 0.60 | 0.20 |

24/17

URS

PROJECT: Double Cell - Four Web Box - 64.125' Wide (Mainline - Case III-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.24 | 0.10 | 0.45 | 0.15 |
| HL-93 | Operating | HL-93 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| HL-93-s | Operating | HL-93-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R1 | Operating | R1 Operating | 0.23 | 0.10 | 0.42 | 0.15 |
| R1-s | Operating | R1-s Operating | 0.23 | 0.10 | 0.42 | 0.15 |
| R2 | Operating | R2 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R2-s | Operating | R2-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R3 | Operating | R3 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R3-s | Operating | R3-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| R4 | Operating | R4 Operating | 0.21 | 0.10 | 0.37 | 0.15 |
| R4-s | Operating | R4-s Operating | 0.21 | 0.10 | 0.37 | 0.15 |
| R5 | Operating | R5 Operating | 0.23 | 0.10 | 0.41 | 0.15 |
| R5-s | Operating | R5-s Operating | 0.23 | 0.10 | 0.41 | 0.15 |
| S1 | Operating | S1 Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S1-s | Operating | S1-s Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S2 | Operating | S2 Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S2-s | Operating | S2-s Operating | 0.22 | 0.10 | 0.40 | 0.15 |
| S3 | Operating | S3 Operating | 0.27 | 0.10 | 0.49 | 0.15 |
| S3-s | Operating | S3-s Operating | 0.27 | 0.10 | 0.49 | 0.15 |
| S4 | Operating | S4 Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| S4-s | Operating | S4-s Operating | 0.21 | 0.10 | 0.38 | 0.15 |
| S5 | Operating | S5 Operating | 0.25 | 0.10 | 0.46 | 0.15 |
| S5-s | Operating | S5-s Operating | 0.25 | 0.10 | 0.46 | 0.15 |

**URS**

PROJECT: Double Cell -Four Web Box - 71.105' Wide (Mainline - Case III-B)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

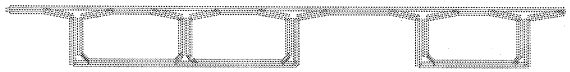
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.23 | 0.09 | 0.43 | 0.14 |
| HL-93 | Operating | HL-93 Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| HL-93-s | Operating | HL-93-s Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R1 | Operating | R1 Operating | 0.22 | 0.09 | 0.40 | 0.14 |
| R1-s | Operating | R1-s Operating | 0.22 | 0.09 | 0.40 | 0.14 |
| R2 | Operating | R2 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R2-s | Operating | R2-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R3 | Operating | R3 Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R3-s | Operating | R3-s Operating | 0.19 | 0.09 | 0.36 | 0.14 |
| R4 | Operating | R4 Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R4-s | Operating | R4-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| R5 | Operating | R5 Operating | 0.22 | 0.09 | 0.39 | 0.14 |
| R5-s | Operating | R5-s Operating | 0.22 | 0.09 | 0.39 | 0.14 |
| S1 | Operating | S1 Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S1-s | Operating | S1-s Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S2 | Operating | S2 Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S2-s | Operating | S2-s Operating | 0.21 | 0.09 | 0.39 | 0.14 |
| S3 | Operating | S3 Operating | 0.25 | 0.09 | 0.47 | 0.14 |
| S3-s | Operating | S3-s Operating | 0.25 | 0.09 | 0.47 | 0.14 |
| S4 | Operating | S4 Operating | 0.20 | 0.09 | 0.37 | 0.14 |
| S4-s | Operating | S4-s Operating | 0.20 | 0.09 | 0.37 | 0.14 |
| S5 | Operating | S5 Operating | 0.23 | 0.09 | 0.44 | 0.14 |
| S5-s | Operating | S5-s Operating | 0.23 | 0.09 | 0.44 | 0.14 |

8/4/19

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.28 | 0.12 | 0.53 | 0.19 |
| HL-93 | Operating | HL-93 Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.25 | 0.12 | 0.45 | 0.19 |
| R1 | Operating | R1 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R2 | Operating | R2 Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R3 | Operating | R3 Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R4 | Operating | R4 Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R5 | Operating | R5 Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1 | Operating | S1 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S2 | Operating | S2 Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S3 | Operating | S3 Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S4 | Operating | S4 Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S5 | Operating | S5 Operating | 0.35 | 0.12 | 0.64 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.35 | 0.12 | 0.64 | 0.19 |

8.4/20

URS

PROJECT: Single Cell - Two Web Box 28.34' Wide (Ramps - Case V-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.06 | 0.04 | 0.12 | 0.04 |
| HL-93 | Operating | HL-93 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| HL-93-s | Operating | HL-93-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| R1 | Operating | R1 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R1-s | Operating | R1-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R2 | Operating | R2 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R2-s | Operating | R2-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R3 | Operating | R3 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R3-s | Operating | R3-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R4 | Operating | R4 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R4-s | Operating | R4-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| R5 | Operating | R5 Operating | 0.06 | 0.04 | 0.11 | 0.04 |
| R5-s | Operating | R5-s Operating | 0.06 | 0.04 | 0.11 | 0.04 |
| S1 | Operating | S1 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S1-s | Operating | S1-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S2 | Operating | S2 Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S2-s | Operating | S2-s Operating | 0.06 | 0.04 | 0.10 | 0.04 |
| S3 | Operating | S3 Operating | 0.06 | 0.04 | 0.13 | 0.04 |
| S3-s | Operating | S3-s Operating | 0.06 | 0.04 | 0.13 | 0.04 |
| S4 | Operating | S4 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S4-s | Operating | S4-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S5 | Operating | S5 Operating | 0.05 | 0.04 | 0.09 | 0.04 |
| S5-s | Operating | S5-s Operating | 0.05 | 0.04 | 0.09 | 0.04 |

8.4/21

URS

PROJECT: Single Cell - Two Web Box - 41.0' Wide (Ramps - Case V-B)

DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue

Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09

CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

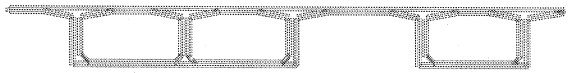
| Section | Inventory / Operating | Combined Name | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| | | | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.12 | 0.03 | 0.36 | 0.02 |
| HL-93 | Operating | HL-93 Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| HL-93-s | Operating | HL-93-s Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| R1 | Operating | R1 Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R1-s | Operating | R1-s Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R2 | Operating | R2 Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R2-s | Operating | R2-s Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R3 | Operating | R3 Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R4 | Operating | R4 Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R5 | Operating | R5 Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| R5-s | Operating | R5-s Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| S1 | Operating | S1 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S1-s | Operating | S1-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2 | Operating | S2 Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2-s | Operating | S2-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S3 | Operating | S3 Operating | 0.12 | 0.03 | 0.33 | 0.02 |
| S3-s | Operating | S3-s Operating | 0.12 | 0.03 | 0.33 | 0.02 |
| S4 | Operating | S4 Operating | 0.08 | 0.03 | 0.27 | 0.02 |
| S4-s | Operating | S4-s Operating | 0.08 | 0.03 | 0.27 | 0.02 |
| S5 | Operating | S5 Operating | 0.07 | 0.03 | 0.08 | 0.02 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.03 | 0.08 | 0.02 |

8.4/22

URS

PROJECT: Cline Avenue-Single Box Portion of Section IVA-( Case VC)
DESCRIPTION: Superstructure - Transverse Analysis
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



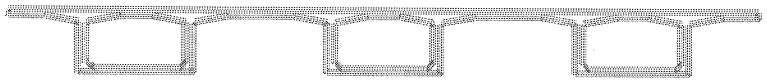
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93 | Inventory | HL-93 Inventory | 0.20 | 0.03 | 0.40 | 0.07 |
| HL-93 | Operating | HL-93 Operating | 0.16 | 0.03 | 0.32 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.16 | 0.03 | 0.32 | 0.07 |
| R1 | Operating | R1 Operating | 0.18 | 0.03 | 0.37 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.18 | 0.03 | 0.37 | 0.07 |
| R2 | Operating | R2 Operating | 0.17 | 0.03 | 0.35 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.17 | 0.03 | 0.35 | 0.07 |
| R3 | Operating | R3 Operating | 0.20 | 0.03 | 0.40 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.20 | 0.03 | 0.40 | 0.07 |
| R4 | Operating | R4 Operating | 0.19 | 0.03 | 0.38 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.19 | 0.03 | 0.38 | 0.07 |
| R5 | Operating | R5 Operating | 0.20 | 0.03 | 0.41 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.20 | 0.03 | 0.41 | 0.07 |
| S1 | Operating | S1 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S2 | Operating | S2 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S3 | Operating | S3 Operating | 0.28 | 0.03 | 0.54 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.28 | 0.03 | 0.54 | 0.07 |
| S4 | Operating | S4 Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.23 | 0.03 | 0.45 | 0.07 |
| S5 | Operating | S5 Operating | 0.28 | 0.03 | 0.55 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.28 | 0.03 | 0.55 | 0.07 |

URS

PROJECT: Cline Avenue-Triple Cell - 6 Web Box, 111.33' Wide (Case I-A)
DESCRIPTION: Striped Lanes - Transverse Analysis
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



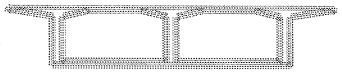
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.18 | 0.10 | 0.31 | 0.16 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| R1-s | Operating | R1-s Operating | 0.17 | 0.10 | 0.28 | 0.16 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.10 | 0.26 | 0.16 |
| R3-s | Operating | R3-s Operating | 0.15 | 0.10 | 0.29 | 0.16 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.10 | 0.29 | 0.16 |
| R5-s | Operating | R5-s Operating | 0.17 | 0.10 | 0.31 | 0.16 |
| S1-s | Operating | S1-s Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S2-s | Operating | S2-s Operating | 0.17 | 0.10 | 0.33 | 0.16 |
| S3-s | Operating | S3-s Operating | 0.20 | 0.10 | 0.39 | 0.16 |
| S4-s | Operating | S4-s Operating | 0.18 | 0.10 | 0.32 | 0.16 |
| S5-s | Operating | S5-s Operating | 0.19 | 0.10 | 0.38 | 0.16 |

URS

PROJECT: Double Cell - Three Web Box, 48'-4" Wide ( Ramps - Case II-A)
DESCRIPTION: Superstructure - Transverse Analysis Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

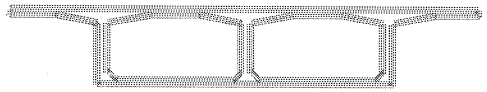
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.09 | 0.05 | 0.25 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.07 | 0.05 | 0.19 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.08 | 0.05 | 0.22 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.09 | 0.05 | 0.24 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.07 | 0.05 | 0.21 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.09 | 0.05 | 0.20 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.07 | 0.05 | 0.16 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.05 | 0.20 | 0.07 |

8.4/25

URS

PROJECT: Double Cell - Three Web Box - 55.625' Wide (Mainline - Case II-B)
DESCRIPTION: STRIPED LANES - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

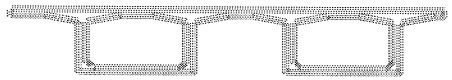
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.16 | 0.12 | 0.28 | 0.20 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.12 | 0.26 | 0.20 |
| R1-s | Operating | R1-s Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.12 | 0.27 | 0.20 |
| R3-s | Operating | R3-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| R5-s | Operating | R5-s Operating | 0.16 | 0.12 | 0.28 | 0.20 |
| S1-s | Operating | S1-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S2-s | Operating | S2-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S3-s | Operating | S3-s Operating | 0.18 | 0.12 | 0.33 | 0.20 |
| S4-s | Operating | S4-s Operating | 0.17 | 0.12 | 0.30 | 0.20 |
| S5-s | Operating | S5-s Operating | 0.18 | 0.12 | 0.33 | 0.20 |

8.4/26

URS

PROJECT: Double Cell - Four Web Box - 64.125' Wide (Mainline - Case III-A)
DESCRIPTION: STRIPED LANES - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.14 | 0.10 | 0.29 | 0.15 |
| HL-93-s | Operating | HL-93-s Operating | 0.13 | 0.10 | 0.22 | 0.15 |
| R1-s | Operating | R1-s Operating | 0.12 | 0.10 | 0.26 | 0.15 |
| R2-s | Operating | R2-s Operating | 0.12 | 0.10 | 0.24 | 0.15 |
| R3-s | Operating | R3-s Operating | 0.13 | 0.10 | 0.27 | 0.15 |
| R4-s | Operating | R4-s Operating | 0.14 | 0.10 | 0.27 | 0.15 |
| R5-s | Operating | R5-s Operating | 0.14 | 0.10 | 0.29 | 0.15 |
| S1-s | Operating | S1-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S2-s | Operating | S2-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S3-s | Operating | S3-s Operating | 0.19 | 0.10 | 0.40 | 0.15 |
| S4-s | Operating | S4-s Operating | 0.15 | 0.10 | 0.32 | 0.15 |
| S5-s | Operating | S5-s Operating | 0.19 | 0.10 | 0.39 | 0.15 |

8.4/27

URS

PROJECT: Double Cell -Four Web Box - 71.105' Wide (Mainline - Case III-B)
DESCRIPTION: Striped Lanes - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

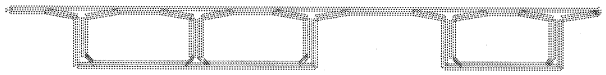
| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.18 | 0.09 | 0.32 | 0.14 |
| HL-93-s | Operating | HL-93-s Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| R1-s | Operating | R1-s Operating | 0.17 | 0.09 | 0.30 | 0.14 |
| R2-s | Operating | R2-s Operating | 0.15 | 0.09 | 0.26 | 0.14 |
| R3-s | Operating | R3-s Operating | 0.15 | 0.09 | 0.27 | 0.14 |
| R4-s | Operating | R4-s Operating | 0.16 | 0.09 | 0.29 | 0.14 |
| R5-s | Operating | R5-s Operating | 0.17 | 0.09 | 0.31 | 0.14 |
| S1-s | Operating | S1-s Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S2-s | Operating | S2-s Operating | 0.18 | 0.09 | 0.32 | 0.14 |
| S3-s | Operating | S3-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |
| S4-s | Operating | S4-s Operating | 0.18 | 0.09 | 0.33 | 0.14 |
| S5-s | Operating | S5-s Operating | 0.20 | 0.09 | 0.36 | 0.14 |

2.4/28

URS

PROJECT: Triple Cell- Five Web Box, 87.34' Wide ( Case IV-A)
DESCRIPTION: Striped Lanes - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.28 | 0.12 | 0.52 | 0.19 |
| HL-93-s | Operating | HL-93-s Operating | 0.24 | 0.12 | 0.44 | 0.19 |
| R1-s | Operating | R1-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R2-s | Operating | R2-s Operating | 0.26 | 0.12 | 0.45 | 0.19 |
| R3-s | Operating | R3-s Operating | 0.28 | 0.12 | 0.49 | 0.19 |
| R4-s | Operating | R4-s Operating | 0.27 | 0.12 | 0.49 | 0.19 |
| R5-s | Operating | R5-s Operating | 0.28 | 0.12 | 0.51 | 0.19 |
| S1-s | Operating | S1-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S2-s | Operating | S2-s Operating | 0.31 | 0.12 | 0.55 | 0.19 |
| S3-s | Operating | S3-s Operating | 0.34 | 0.12 | 0.62 | 0.19 |
| S4-s | Operating | S4-s Operating | 0.31 | 0.12 | 0.56 | 0.19 |
| S5-s | Operating | S5-s Operating | 0.35 | 0.12 | 0.64 | 0.19 |

8/4/29

URS

PROJECT: Single Cell - Two Web Box 28.34' Wide (Ramps - Case V-A)
DESCRIPTION: Superstructure - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.03 | 0.04 | 0.10 | 0.04 |
| HL-93-s | Operating | HL-93-s Operating | 0.03 | 0.04 | 0.07 | 0.04 |
| R1-s | Operating | R1-s Operating | 0.03 | 0.04 | 0.08 | 0.04 |
| R2-s | Operating | R2-s Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R3-s | Operating | R3-s Operating | 0.04 | 0.04 | 0.06 | 0.04 |
| R4-s | Operating | R4-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| R5-s | Operating | R5-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S1-s | Operating | S1-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S2-s | Operating | S2-s Operating | 0.04 | 0.04 | 0.07 | 0.04 |
| S3-s | Operating | S3-s Operating | 0.03 | 0.04 | 0.10 | 0.04 |
| S4-s | Operating | S4-s Operating | 0.04 | 0.04 | 0.05 | 0.04 |
| S5-s | Operating | S5-s Operating | 0.03 | 0.04 | 0.05 | 0.04 |

URS

PROJECT: Single Cell - Two Web Box - 41.0' Wide (Ramps - Case V-B)
DESCRIPTION: Striped Lanes - Transverse Analysis - Cline Avenue
Area of Steel Requirements

CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:

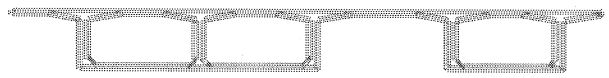
**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.12 | 0.03 | 0.36 | 0.02 |
| HL-93-s | Operating | HL-93-s Operating | 0.09 | 0.03 | 0.28 | 0.02 |
| R1-s | Operating | R1-s Operating | 0.11 | 0.03 | 0.31 | 0.02 |
| R2-s | Operating | R2-s Operating | 0.09 | 0.03 | 0.26 | 0.02 |
| R3-s | Operating | R3-s Operating | 0.07 | 0.03 | 0.25 | 0.02 |
| R4-s | Operating | R4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| R5-s | Operating | R5-s Operating | 0.11 | 0.03 | 0.32 | 0.02 |
| S1-s | Operating | S1-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S2-s | Operating | S2-s Operating | 0.10 | 0.03 | 0.30 | 0.02 |
| S3-s | Operating | S3-s Operating | 0.13 | 0.03 | 0.37 | 0.02 |
| S4-s | Operating | S4-s Operating | 0.09 | 0.03 | 0.29 | 0.02 |
| S5-s | Operating | S5-s Operating | 0.07 | 0.03 | 0.23 | 0.02 |

URS

PROJECT: Cline Avenue-Single Box Portion of Section IVA-( Case VC)
DESCRIPTION: Striped Lanes - Transverse Analysis
Area of Steel Requirements

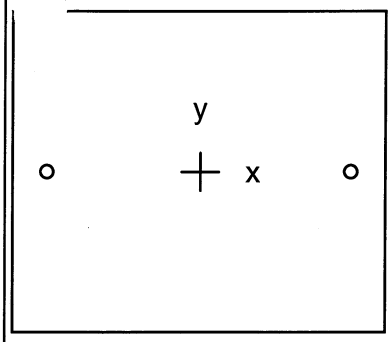
CALCS BY: PT DATE: 9/14/09
CHECKED BY: DATE:



**LOADS WERE CALCULATED USING BRUG 5.75.44 - and Effective Span Length**

| | | | Middle of Web | | Top of Web | |
|---|---|---|---|---|---|---|
| Section | Inventory / Operating | Combined Name | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd | $A_b$ req'd ($in^2/ft$) | $A_{b\ Dead}$ req'd ($in^2/ft$) |
| HL-93-s | Inventory | HL-93-s Inventory | 0.16 | 0.03 | 0.31 | 0.07 |
| HL-93-s | Operating | HL-93-s Operating | 0.13 | 0.03 | 0.26 | 0.07 |
| R1-s | Operating | R1-s Operating | 0.15 | 0.03 | 0.29 | 0.07 |
| R2-s | Operating | R2-s Operating | 0.14 | 0.03 | 0.28 | 0.07 |
| R3-s | Operating | R3-s Operating | 0.17 | 0.03 | 0.33 | 0.07 |
| R4-s | Operating | R4-s Operating | 0.17 | 0.03 | 0.32 | 0.07 |
| R5-s | Operating | R5-s Operating | 0.18 | 0.03 | 0.34 | 0.07 |
| S1-s | Operating | S1-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S2-s | Operating | S2-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S3-s | Operating | S3-s Operating | 0.25 | 0.03 | 0.48 | 0.07 |
| S4-s | Operating | S4-s Operating | 0.20 | 0.03 | 0.39 | 0.07 |
| S5-s | Operating | S5-s Operating | 0.25 | 0.03 | 0.48 | 0.07 |

8.4/33




14 x 12 in

Code: ACI 318-02

Units: English

Run axis: About Y-axis

Run option: Investigation

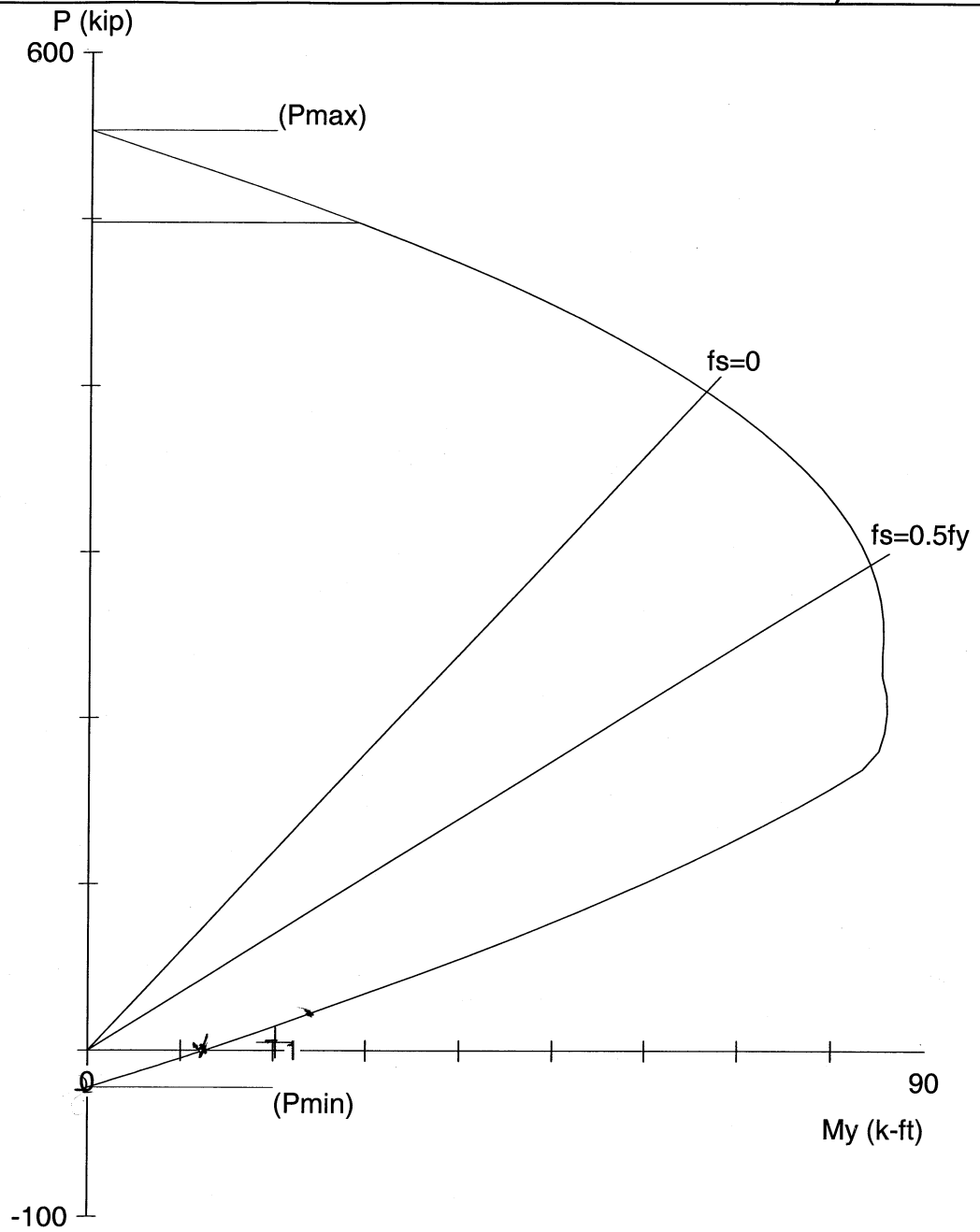
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 09/14/09

Time: 15:25:47




pcaColumn v4.10. Licensed to: URS Corporation. License ID: 54317-1014124-4-1BE58-33580

File: C:\Documents and Settings\brg_rjb\Desktop\cline1.col

Project: Cline

Column: Engineer: RJB

| | | | |
|---|---|---|---|
| f'c = 5 ksi | fy = 60 ksi | Ag = 168 in^2 | 2 #4 bars |
| Ec = 4031 ksi | Es = 29000 ksi | As = 0.41 in^2 | rho = 0.25% |
| fc = 4.25 ksi | | Xo = 0.00 in | Ix = 2016 in^4 |
| u = 0.003 in/in | | Yo = 0.00 in | Iy = 2744 in^4 |
| Beta1 = 0.8 | | Min clear spacing = 10.86 in | Clear cover = 1.06 in |
| Confinement: Other | phi(a) = 0.9, phi(b) = 0.9, phi(c) = 0.75 | | |

8.4/34

```
                                  OOOOO
                                 OO   OO
                                 OO   OO
OOOOOOO    OOOOO   OOOOO   OO        OOOOO   OO    OO   OO   OOOOOOOO    OOOO
OO    OO  OO      OO   OO  OO       OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OO    OO  OO      OOOOOOO  OO   OO  OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OOOOOOO   OO      OO   OO  OO   OO  OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OO         OOOOO  OO   OO   OOOOO    OOOOO   OOOOO  OOOOO   OO   OO  OO  OO   OO (TM)
```

==========
pcaColumn v4.10 (TM)
Computer program for the Strength Design of Reinforced Concrete Sections
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8.4/35

General Information:
==========

File Name: C:\Documents and Settings\brg_rjb\Desktop\cline1.col
Project: Cline
Column: Engineer: RJB
Code: ACI 318-02 Units: English

Run Option: Investigation Slenderness: Not considered
Run Axis: Y-axis Column Type: Structural

Material Properties:
==========

f'c = 5 ksi fy = 60 ksi
Ec = 4030.51 ksi Es = 29000 ksi
Ultimate strain = 0.003 in/in
Beta1 = 0.8

Section:
==========

Rectangular: Width = 14 in Depth = 12 in

Gross section area, Ag = 168 in^2
Ix = 2016 in^4 Iy = 2744 in^4
Xo = 0 in Yo = 0 in

Reinforcement:
==========

Bar Set: ASTM A615

| Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) |
|---|---|---|---|---|---|---|---|---|
| # 3 | 0.38 | 0.11 | # 4 | 0.50 | 0.20 | # 5 | 0.63 | 0.31 |
| # 6 | 0.75 | 0.44 | # 7 | 0.88 | 0.60 | # 8 | 1.00 | 0.79 |
| # 9 | 1.13 | 1.00 | # 10 | 1.27 | 1.27 | # 11 | 1.41 | 1.56 |
| # 14 | 1.69 | 2.25 | # 18 | 2.26 | 4.00 | | | |

Confinement: Other; #3 ties with #10 bars, #4 with larger bars.
phi(a) = 0.9, phi(b) = 0.9, phi(c) = 0.75

Pattern: Irregular

Total steel area, As = 0.41 in^2 at 0.25% (Note: rho < 0.50%)

| Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|
| 0.21 | -5.7 | 0.0 | 0.21 | 5.7 | 0.0 | | | |

Factored Loads and Moments with Corresponding Capacities:
==========

| No. | Pu kip | Muy k-ft | fMny k-ft | fMn/Mu | N.A. depth in | eps_t | Phi |
|---|---|---|---|---|---|---|---|
| 1 | 4.90 | 20.26 | 15.22 | 0.751 | 0.74 | 0.04828 | 0.900# |

# Section capacity exceeded!

*** End of output ***

$S_{bc}$ = Composite section modulus for the extreme fiber of section

$S_b$ = Non-composite section modulus for the extreme fiber of section

### 6.5.8 Evaluation for Flexural and Axial Force Effects

Members such as arches and beam-columns that are subjected to a combination of axial load and moment shall be evaluated by considering the effect on load capacity of the interaction of axial and bending load effects. Rating factors should be obtained based on both the moment capacity and axial capacity.

### C6.5.8

The use of interaction diagrams as capacity evaluation aids is recommended. The interaction diagram represents all possible combinations of axial loads and bending moments that could produce failure of a particular section in its current condition. The intersection of the line representing dead-load and live-load eccentricities with the interaction curve provides a convenient method for evaluating load capacity (see Appendix C.6.1 to this section).

### 6.5.9 Evaluation for Shear

The shear capacity of existing reinforced and prestressed concrete bridge members should be evaluated for permit loads. In-service concrete bridges that show no visible signs of shear distress need not be checked for shear when rating for the design load or legal loads.

When using the Modified Compression Field Theory (MCFT) for the evaluation of concrete shear resistance, the longitudinal reinforcement should be checked for the increased tension caused by shear, in accordance with LRFD Article 5.8.3.5.

### C6.5.9

Design provisions based on the Modified Compression Field Theory are incorporated in the LRFD specifications. The MCFT is capable of giving more accurate predictions of the shear response of existing reinforced and prestressed concrete bridge members, with and without web reinforcement. In lieu of the more detailed analysis outlined in the LRFD specifications, a simplified analysis that assumes $\beta = 2.0$ and $\theta = 45°$ may be first attempted for reinforced concrete sections and standard prestressed concrete sections with transverse reinforcement. The expressions for shear strength then become essentially identical to those traditionally used for evaluating shear resistance. Where necessary, a more accurate evaluation using MCFT may be performed.

Live-load shear for existing bridge girders using the LRFD specifications could be higher than the shear obtained from the AASHTO *Standard Specifications* due to higher live load, higher live-load distribution factors for shear, and the higher dynamic load allowance. On the other hand, LRFD specifications may yield higher shear resistance for prestressed concrete sections at high-shear locations. MCFT uses the variable angle ($\theta$) truss model to determine shear resistance. Higher prestress levels give flatter $\theta$ angles. Flatter $\theta$ angles could give higher shear resistances except at regions with high moment and shear.

Prestressed concrete shear capacities are load dependent, which means computing the shear capacity involves an iterative process when using the current AASHTO MCFT. Multiple locations, preferably at 0.05 points, need to be checked for shear. Location where shear is highest may not be critical because the corresponding moment may be

8.4/37



VEH: S3 - SPECIAL TR BRUG(5.75.44) page 35
date 11/09/2009; time 13:23:34
ine Avenue - Load Rating - Double Box Mainline - 4 Webs -

Slab 7 section b

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0406 | -5.3301 | -0.0061 | -0.5056 |
| 2 | 11.000 | -0.0077 | -1.2389 | -0.0056 | -0.3664 |
| | 19.458 | 0.0087 | 0.9740 | -0.0026 | -0.2173 |
| 4 | 27.917 | 0.0045 | 0.7268 | -0.0005 | -0.0843 |
| | 36.375 | 0.0025 | 0.4636 | -0.0001 | -0.0292 |
| 6 | 44.833 | 0.0021 | 0.3286 | -0.0001 | -0.0143 |
| 8 | 55.625 | 0.0003 | 0.0017 | 0.0000 | 0.0171 |
| Area | | -0.1338 | -18.1648 | -0.1156 | -9.1461 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | -2.694 | -2.694 | -1.055 | -1.055 |
| Topping | -0.454 | -0.454 | -0.229 | -0.229 |
| Linear loads | -2.220 | -2.220 | -0.212 | -0.212 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 4.801 | -9.547 | -1.050 | -2.625 |
| Total | -0.566 | -14.914 | -2.545 | -4.120 |

Maximum moment : 2 vehicle(s) decisive
Location of wheels z =
17.96 19.46 23.96 25.46
27.96 29.46 33.96 35.46

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
2.92 4.42 8.92 10.42

$P_u = 0.9(-1.055 - 0.229 - 0.212) + 1.35(-2.625) = \underline{-4.9\,k}$ (-1.35 k) (-3.55 k)

$M_u = 1.25(-2.69) + 1.5(-0.45 - 2.22) + 1.35(-9.55) = \underline{-20.26}$ (-7.37) (-12.89)

M for 4.9 k

$R.F. = \dfrac{15.22 - 7.37}{12.89} = \underline{0.61}$

URS

Project: Double Cell - Three Web Box - 55.625' Wide (Mainline - Case II-B) | Design: PT | Date: 9/14/2009

Portion: Superstructure - Transverse Analysis - Cline Avenue | Check: | Date:

FILE: V:\Projects\Cline Avenue\Load Rating Analysis\Transverse Analysis\Spreadsheet_AASHTO_lanes_5.75.44 Revised Length\[Transverse Load Rating Section EL IIB.XLS]StrengthI(W)L

Operating - Strength I

**Area of Steel Required at Webs due to Transverse Bending**

Concrete Strength, 5000 psi

Steel Strength, Fsy 60,000 psi

Worksheet source

| | |
|---|---|
| One or two vehicles: | LLMultiple |
| One vehicle with HL93: | LLHL93 |
| One or two vehicles: | LLSingle |
| SW, WS, Barrier: | DC&PTBrug |

Truck ID: 16 — Truck 16 - S3 + HL93

Combine trucks?: Y

| | One or two | One Vehicle | One or two vehicles | One Vehicle |
|---|---|---|---|---|
| MPF = | 1.00 | 1.00 | 1.00 | 1.00 |
| LF = | 1.25 | 1.50 | 1.35 | 1.35 |

Minimum Live Load Moment

Calculate Area of Steel Required at Top of Webs

| SECTION | M (DL) kip-ft | M (SDL) kip-ft | LL+I (Min) kip-ft | LL+I (Min) kip-ft | Controlling # vehicles | Mu (min) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft | LL+I (Max) kip-ft | LL+I (Max) kip-ft | Controlling # vehicles | Mu (max) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft | Mu (max) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 a | -3.70 | -4.89 | -18.45 | -18.45 | 1 | -36.87 | 0.588 | -12.688 | 7.76 | 0.63 | 7.15 | 5.80 | 2 | -2.31 | 0.588 | -12.688 | 0.49 | 0.04 | -11.96 | 0.588 | -12.688 | 2.52 | 0.200 |
| 8 a | -0.01 | -0.01 | -14.16 | -10.97 | 2 | -19.15 | 0.588 | -12.688 | 4.03 | 0.32 | 14.15 | 10.96 | 2 | 19.07 | 0.588 | -12.688 | 4.01 | 0.32 | -0.03 | 0.588 | -12.688 | 0.01 | 0.001 |
| 9 a | -3.53 | -4.80 | -17.94 | -17.94 | 1 | -35.82 | 0.588 | -12.688 | 7.54 | 0.61 | 7.15 | 5.80 | 2 | -1.95 | 0.588 | -12.688 | 0.41 | 0.03 | -11.61 | 0.588 | -12.688 | 2.44 | 0.194 |

Calculate Area of Steel Required at Middle of Webs

| SECTION | M (DL) kip-ft | M (SDL) kip-ft | LL+I (Min) kip-ft | LL+I (Min) kip-ft | Controlling # vehicles | Mu (min) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft | LL+I (Max) kip-ft | LL+I (Max) kip-ft | Controlling # vehicles | Mu (max) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft | Mu (max) kip-ft | $a_1$ | $b_1$ | $c_1$ | As (min) in^2/ft |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 b | -2.69 | -2.67 | -9.55 | -9.55 | 1 | -20.27 | 0.588 | -12.688 | 4.27 | 0.34 | 3.91 | 3.26 | 2 | -2.10 | 0.588 | -12.688 | 0.44 | 0.03 | -7.38 | 0.588 | -12.688 | 1.55 | 0.123 |
| 8 b | -0.01 | -0.01 | -6.79 | -5.37 | 2 | -9.19 | 0.588 | -12.688 | 1.94 | 0.15 | 6.77 | 5.36 | 2 | 9.11 | 0.588 | -12.688 | 1.92 | 0.15 | -0.02 | 0.588 | -12.688 | 0.01 | 0.000 |
| 9 b | -2.60 | -2.62 | -9.27 | -9.27 | 1 | -19.69 | 0.588 | -12.688 | 4.15 | 0.33 | 3.91 | 3.26 | 2 | -1.90 | 0.588 | -12.688 | 0.40 | 0.03 | -7.18 | 0.588 | -12.688 | 1.51 | 0.120 |

2.4/38

8.4/39

| P | M | % Inc. in M |
|---|---|---|
| 0 | 12.59 | 0.0% |
| 1 | 13.00 | 3.3% |
| 2 | 13.42 | 6.6% |
| 3 | 13.83 | 9.8% |
| 4 | 14.24 | 13.1% |
| 5 | 14.66 | 16.4% |
| 6 | 15.07 | 19.7% |
| 7 | 15.48 | 23.0% |
| 8 | 15.89 | 26.3% |
| 9 | 16.31 | 29.5% |
| 10 | 16.72 | 32.8% |
| 11 | 17.13 | 36.1% |
| 12 | 17.55 | 39.4% |
| 13 | 17.96 | 42.7% |
| 14 | 18.37 | 45.9% |
| 15 | 18.79 | 49.2% |
| 16 | 19.20 | 52.5% |
| 17 | 19.61 | 55.8% |
| 18 | 20.03 | 59.1% |
| 19 | 20.44 | 62.3% |
| 20 | 20.85 | 65.6% |

8.4/40

```
                                  OOOOO
                                 OO   OO
                                 OO   OO
OOOOOOO    OOOOO   OOOOO         OO        OOOOO   OO    OO    OO   OOOOOOOO    OOOO
OO    OO  OO      OO   OO        OO       OO   OO  OO    OO    OO  OO   OO  OO   OO  OO
OO    OO  OO      OOOOOOO        OO   OO  OO   OO  OO    OO    OO  OO   OO  OO   OO  OO
OOOOOOO   OO      OO   OO        OO   OO  OO   OO  OO    OO    OO  OO   OO  OO   OO  OO
OO         OOOOO  OO   OO         OOOOO    OOOOO   OOOOO  OOOOO   OO   OO  OO   OO  OO (TM)
```

==========

pcaColumn v4.10 (TM)
Computer program for the Strength Design of Reinforced Concrete Sections
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==========

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8.4/41

General Information:
==========

File Name: C:\Documents and Settings\brg_rjb\Desktop\cline1.col
Project: Cline
Column:
Code: ACI 318-02

Engineer: RJB
Units: English

Run Option: Investigation
Run Axis: Y-axis

Slenderness: Not considered
Column Type: Structural

Material Properties:
==========

f'c = 5 ksi
Ec = 4030.51 ksi
Ultimate strain = 0.003 in/in
Beta1 = 0.8

fy = 60 ksi
Es = 29000 ksi

Section:
==========

Rectangular: Width = 14 in

Depth = 12 in

Gross section area, Ag = 168 in^2
Ix = 2016 in^4
Xo = 0 in

Iy = 2744 in^4
Yo = 0 in

Reinforcement:
==========

Bar Set: ASTM A615

| Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) |
|---|---|---|---|---|---|---|---|---|
| # 3 | 0.38 | 0.11 | # 4 | 0.50 | 0.20 | # 5 | 0.63 | 0.31 |
| # 6 | 0.75 | 0.44 | # 7 | 0.88 | 0.60 | # 8 | 1.00 | 0.79 |
| # 9 | 1.13 | 1.00 | # 10 | 1.27 | 1.27 | # 11 | 1.41 | 1.56 |
| # 14 | 1.69 | 2.25 | # 18 | 2.26 | 4.00 | | | |

Confinement: Other; #3 ties with #10 bars, #4 with larger bars.
phi(a) = 0.9, phi(b) = 0.9, phi(c) = 0.75

Pattern: Irregular

Total steel area, As = 0.41 in^2 at 0.25% (Note: rho < 0.50%)

| Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|
| 0.21 | -5.7 | 0.0 | 0.21 | 5.7 | 0.0 | | | |

Control Points:
==========

| Bending about | Axial Load P kip | X-Moment k-ft | Y-Moment k-ft | N.A. depth in | eps_t | Phi |
|---|---|---|---|---|---|---|
| Y @ Max compression | 552.8 | -0.00 | 0.00 | 40.88 | -0.00207 | 0.750 |
| @ Allowable comp. | 497.5 | -0.00 | 28.95 | 15.91 | -0.00061 | 0.750 |
| @ fs = 0.0 | 396.9 | 0.00 | 66.38 | 12.69 | 0.00000 | 0.750 |
| @ fs = 0.5*fy | 292.7 | 0.00 | 83.93 | 9.43 | 0.00103 | 0.750 |
| @ Balanced point | 229.1 | 0.00 | 85.04 | 7.51 | 0.00207 | 0.750 |
| @ Tension Control | 173.9 | 0.00 | 84.43 | 4.76 | 0.00500 | 0.900 |
| @ Pure bending | 0.0 | -0.00 | 12.59 | 0.61 | 0.05951 | 0.900 |
| @ Max tension | -22.4 | 0.00 | -0.00 | 0.00 | 9.99999 | 0.900 |
| -Y @ Max compression | 552.8 | 0.00 | 0.00 | 40.88 | -0.00207 | 0.750 |
| @ Allowable comp. | 497.5 | -0.00 | -28.95 | 15.91 | -0.00061 | 0.750 |
| @ fs = 0.0 | 396.9 | -0.00 | -66.38 | 12.69 | 0.00000 | 0.750 |
| @ fs = 0.5*fy | 292.7 | -0.00 | -83.93 | 9.43 | 0.00103 | 0.750 |
| @ Balanced point | 229.1 | -0.00 | -85.04 | 7.51 | 0.00207 | 0.750 |
| @ Tension Control | 173.9 | -0.00 | -84.43 | 4.76 | 0.00500 | 0.900 |
| @ Pure bending | 0.0 | -0.00 | -12.59 | 0.61 | 0.05951 | 0.900 |
| @ Max tension | -22.4 | 0.00 | -0.00 | 0.00 | 9.99999 | 0.900 |

*** End of output ***

8.4/42

VEH: HL93 TRUCK BRUG(5.75.44) page 52
date 11/09/2009; time 14:43:50
ne Avenue - Striped Lane - Double Box AND SINGLE BOX -

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0211 | -2.0884 | 0.0009 | 0.1941 |
| | 19.250 | -0.0281 | -3.3573 | 0.0017 | 0.1072 |
| | 36.167 | -0.0678 | -4.1477 | -0.0189 | -0.1219 |
| | 54.941 | 0.0749 | 4.1783 | -0.0197 | -0.4373 |
| | 73.174 | 0.0391 | 4.6991 | -0.0033 | -0.4350 |
| 12 | 87.340 | 0.0391 | 4.4194 | -0.0037 | -0.4024 |
| Area | | 0.4320 | 30.5988 | -1.0859 | -16.6464 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 6.684 | 6.684 | -2.941 | -2.941 |
| Topping | 0.765 | 0.765 | -0.416 | -0.416 |
| Linear loads | 1.007 | 1.007 | -0.094 | -0.094 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 11.102 | -8.811 | -3.547 | -3.496 |
| Total | 19.558 | -0.355 | -6.999 | -6.947 |

imum moment : 2 vehicle(s) decisive
Location of wheels z =
48.94 50.44 54.94 56.44
58.94 60.44 64.94 66.44

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
24.67 26.17 30.67 32.17
34.67 36.17 40.67 42.17

VEH: HL93 TRUCK BRUG(5.75.44) page 53
date 11/09/2009; time 14:43:50
ne Avenue - Striped Lane - Double Box AND SINGLE BOX -

Slab 12 section b

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0113 | -1.1172 | 0.0007 | 0.1375 |
| | 19.250 | -0.0137 | -1.7069 | 0.0014 | 0.1041 |
| | 36.167 | -0.0367 | -2.3870 | -0.0091 | -0.0628 |
| | 54.941 | 0.0389 | 2.2436 | -0.0106 | -0.2758 |
| | 73.174 | 0.0213 | 2.5641 | -0.0021 | -0.2715 |
| 12 | 87.340 | 0.0213 | 2.4122 | -0.0023 | -0.2518 |
| Area | | 0.2248 | 16.3430 | -0.5032 | -9.3633 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 4.308 | 4.308 | -1.269 | -1.269 |
| Topping | 0.409 | 0.409 | -0.234 | -0.234 |
| Linear loads | 0.562 | 0.562 | -0.052 | -0.052 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 5.714 | -4.691 | -1.817 | -1.529 |
| Total | 10.992 | 0.587 | -3.371 | -3.084 |

imum moment : 2 vehicle(s) decisive
Location of wheels z =
48.94 50.44 54.94 56.44
58.94 60.44 64.94 66.44

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
24.67 26.17 30.67 32.17
34.67 36.17 40.67 42.17

VEH: HL93 TRUCK - S BRUG(5.75.44) page 52
date 11/09/2009; time 14:43:41
ne Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0211 | -2.0884 | 0.0009 | 0.1941 |
| | 19.250 | -0.0281 | -3.3573 | 0.0017 | 0.1072 |
| | 36.167 | -0.0678 | -4.1477 | -0.0189 | -0.1219 |
| | 54.941 | 0.0749 | 4.1783 | -0.0197 | -0.4373 |
| | 73.174 | 0.0391 | 4.6991 | -0.0033 | -0.4350 |
| 12 | 87.340 | 0.0391 | 4.4194 | -0.0037 | -0.4024 |
| Area | | 0.4320 | 30.5988 | -1.0859 | -16.6464 |

| Description | Moment Max. | Moment Min. | Axial force Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 6.684 | 6.684 | -2.941 | -2.941 |
| Topping | 0.765 | 0.765 | -0.416 | -0.416 |
| Linear loads | 1.007 | 1.007 | -0.094 | -0.094 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 6.274 | -5.383 | -2.903 | -1.300 |
| Total | 14.730 | 3.073 | -6.355 | -4.751 |

imum moment : 1 vehicle(s) decisive
Location of wheels z =
48.94 50.44 54.94 56.44
55.69

$\Delta = 3.23'$ apart

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

8.4/46



VEH: HL93 TRUCK - S BRUG(5.75.44) page 53
date 11/09/2009; time 14:43:41
ne Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section b

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0113 | -1.1172 | 0.0007 | 0.1375 |
| | 19.250 | -0.0137 | -1.7069 | 0.0014 | 0.1041 |
| | 36.167 | -0.0367 | -2.3870 | -0.0091 | -0.0628 |
| | 54.941 | 0.0389 | 2.2436 | -0.0106 | -0.2758 |
| | 73.174 | 0.0213 | 2.5641 | -0.0021 | -0.2715 |
| 12 | 87.340 | 0.0213 | 2.4122 | -0.0023 | -0.2518 |
| Area | | 0.2248 | 16.3430 | -0.5032 | -9.3633 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 4.308 | 4.308 | -1.269 | -1.269 |
| Topping | 0.409 | 0.409 | -0.234 | -0.234 |
| Linear loads | 0.562 | 0.562 | -0.052 | -0.052 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 3.200 | -2.890 | -0.796 | -0.610 |
| Total | 8.478 | 2.388 | -2.350 | -2.165 |

imum moment : 1 vehicle(s) decisive
Location of wheels z =
53.44 54.94 59.44 60.94
60.19 HL93 & SS overlapping

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

VEH: S5 - SUPERLOAD BRUG(5.75.44) page 52
date 11/09/2009; time 14:43:57
'ne Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0095 | -2.0884 | 0.0009 | 0.1941 |
| | 19.250 | -0.0150 | -3.3573 | 0.0006 | 0.1072 |
| | 36.167 | -0.0212 | -4.1477 | -0.0024 | -0.1219 |
| | 54.941 | 0.0214 | 4.1783 | -0.0037 | -0.4373 |
| | 73.174 | 0.0212 | 4.6991 | -0.0019 | -0.4350 |
| 12 | 87.340 | 0.0201 | 4.4194 | -0.0018 | -0.4024 |
| Area | | 0.1480 | 30.5988 | -0.1584 | -16.6464 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 6.684 | 6.684 | -2.941 | -2.941 |
| Topping | 0.765 | 0.765 | -0.416 | -0.416 |
| Linear loads | 1.007 | 1.007 | -0.094 | -0.094 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 27.013 | -22.424 | -2.706 | -0.805 |
| Total | 35.469 | -13.968 | -6.157 | -4.256 |

imum moment : 2 vehicle(s) decisive
Location of wheels z =
58.17 59.67 64.17 65.67
68.17 69.67 74.17 75.67

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
20.17 21.67 26.17 27.67
30.17 31.67 36.17 37.67

VEH: S5 - SUPERLOAD BRUG(5.75.44) page 53
date 11/09/2009; time 14:43:57
'ne Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section b

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0051 | -1.1172 | 0.0006 | 0.1375 |
| | 19.250 | -0.0076 | -1.7069 | 0.0005 | 0.1041 |
| | 36.167 | -0.0118 | -2.3870 | -0.0012 | -0.0628 |
| | 54.941 | 0.0111 | 2.2436 | -0.0022 | -0.2758 |
| | 73.174 | 0.0116 | 2.5641 | -0.0012 | -0.2715 |
| 12 | 87.340 | 0.0109 | 2.4122 | -0.0011 | -0.2518 |
| Area | | 0.0776 | 16.3430 | -0.0822 | -9.3633 |

| Description | Moment Max. | Moment Min. | Axial force Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 4.308 | 4.308 | -1.269 | -1.269 |
| Topping | 0.409 | 0.409 | -0.234 | -0.234 |
| Linear loads | 0.562 | 0.562 | -0.052 | -0.052 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 14.663 | -12.012 | -1.674 | -0.253 |
| Total | 19.942 | -6.734 | -3.228 | -1.807 |

imum moment : 2 vehicle(s) decisive
Location of wheels z =
58.17 59.67 64.17 65.67
68.17 69.67 74.17 75.67

Minimum moment : 2 vehicle(s) decisive
Location of wheels z =
20.17 21.67 26.17 27.67
30.17 31.67 36.17 37.67

VEH: S5 - SUPERLOAD BRUG(5.75.44) page 52
date 11/09/2009; time 14:43:48
ine Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section a

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0095 | -2.0884 | 0.0009 | 0.1941 |
| | 19.250 | -0.0150 | -3.3573 | 0.0006 | 0.1072 |
| | 36.167 | -0.0212 | -4.1477 | -0.0024 | -0.1219 |
| | 54.941 | 0.0214 | 4.1783 | -0.0037 | -0.4373 |
| | 73.174 | 0.0212 | 4.6991 | -0.0019 | -0.4350 |
| 12 | 87.340 | 0.0201 | 4.4194 | -0.0018 | -0.4024 |
| Area | | 0.1480 | 30.5988 | -0.1584 | -16.6464 |

| Description | Moment Max. | Moment Min. | Axial force Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 6.684 | 6.684 | -2.941 | -2.941 |
| Topping | 0.765 | 0.765 | -0.416 | -0.416 |
| Linear loads | 1.007 | 1.007 | -0.094 | -0.094 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 13.734 | -12.369 | -1.497 | -1.054 |
| Total | 22.189 | -3.913 | -4.948 | -4.505 |

imum moment : 1 vehicle(s) decisive
Location of wheels z =
58.17 59.67 64.17 65.67
58.92
Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

VEH: S5 - SUPERLOAD BRUG(5.75.44) page 53
date 11/09/2009; time 14:43:48
ne Avenue - Load Rating - Double Box AND SINGLE BOX - 8

Slab 12 section b

Loadfactor 1.000 impactfactor 1.300

Influence lines incl. loaddistribution

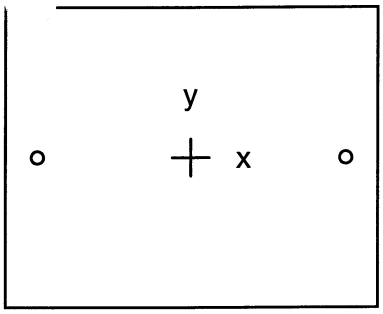
| Load at node | Distance | Moment concentr. | Moment u.d.l. | Axial force concentr. | Axial force u.d.l. |
|---|---|---|---|---|---|
| 1 | 0.000 | -0.0051 | -1.1172 | 0.0006 | 0.1375 |
| | 19.250 | -0.0076 | -1.7069 | 0.0005 | 0.1041 |
| | 36.167 | -0.0118 | -2.3870 | -0.0012 | -0.0628 |
| | 54.941 | 0.0111 | 2.2436 | -0.0022 | -0.2758 |
| | 73.174 | 0.0116 | 2.5641 | -0.0012 | -0.2715 |
| 12 | 87.340 | 0.0109 | 2.4122 | -0.0011 | -0.2518 |
| Area | | 0.0776 | 16.3430 | -0.0822 | -9.3633 |

| Description | Moment Max. | Moment Min. | Axial force in case of Max. mom | Axial force in case of Min. mom |
|---|---|---|---|---|
| Selfweight | 4.308 | 4.308 | -1.269 | -1.269 |
| Topping | 0.409 | 0.409 | -0.234 | -0.234 |
| Linear loads | 0.562 | 0.562 | -0.052 | -0.052 |
| Live load (incl. reduction factor) | | | | |
| Vehicle(s) | 7.436 | -6.781 | -0.863 | -0.501 |
| Total | 12.715 | -1.503 | -2.417 | -2.055 |

imum moment : 1 vehicle(s) decisive
Location of wheels z =
59.67 61.17 65.67 67.17
60.42

Minimum moment : 1 vehicle(s) decisive
Location of wheels z =
30.17 31.67 36.17 37.67

8.4/51




15 x 12 in

Code: ACI 318-02

Units: English

Run axis: About Y-axis

Run option: Investigation

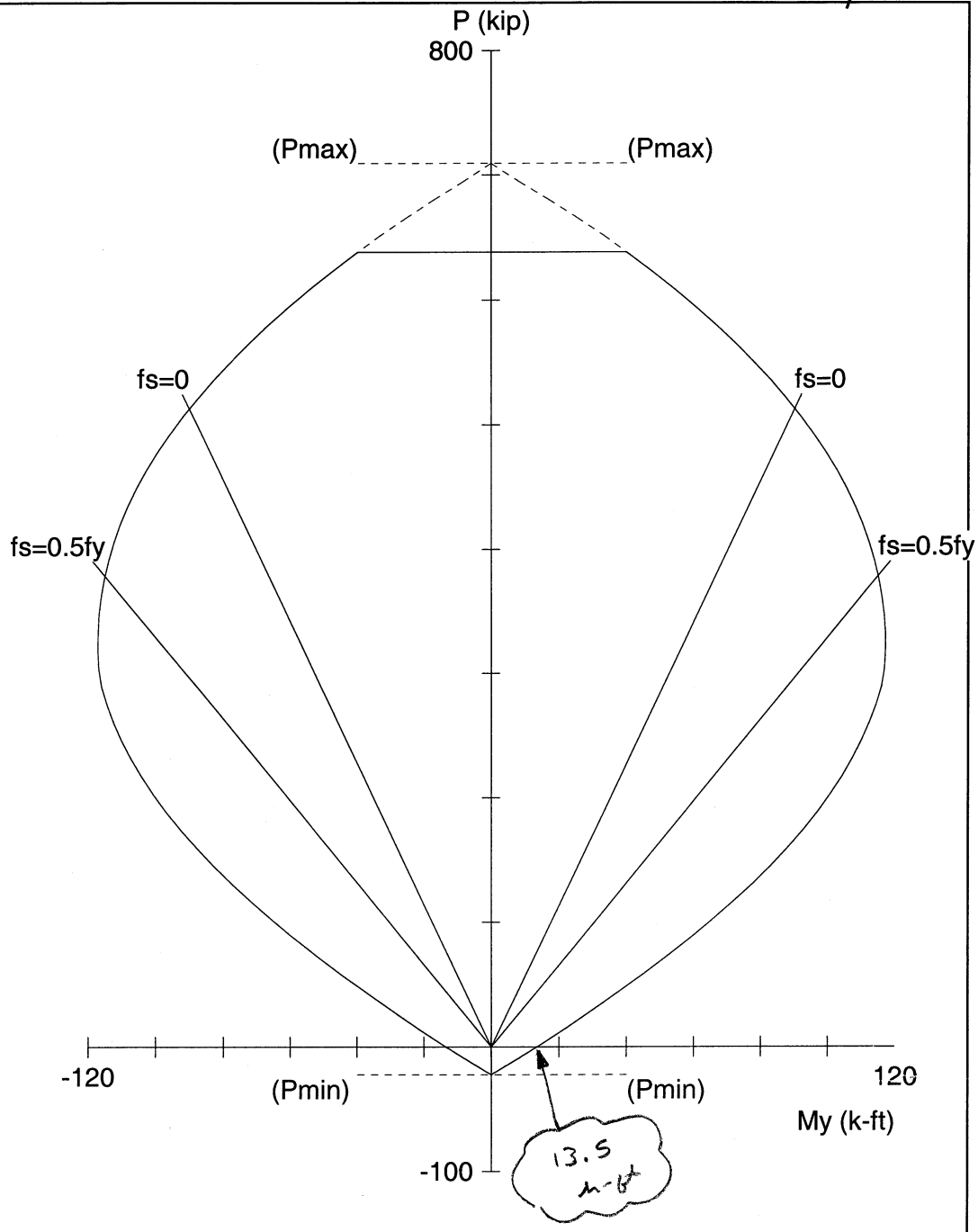
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 09/10/09

Time: 16:56:58




pcaColumn v4.10. Licensed to: URS Corporation. License ID: 54317-1014124-4-1BE58-33580

File: C:\Documents and Settings\brg_rjb\Desktop\cline1.col

Project: Cline

Column: Engineer: RJB

| | | | |
|---|---|---|---|
| f'c = 5 ksi | fy = 60 ksi | Ag = 180 in^2 | 2 #4 bars |
| Ec = 4031 ksi | Es = 29000 ksi | As = 0.41 in^2 | rho = 0.23% |
| fc = 4.25 ksi | | Xo = 0.00 in | Ix = 2160 in^4 |
| u = 0.003 in/in | | Yo = 0.00 in | Iy = 3375 in^4 |
| Beta1 = 0.8 | | Min clear spacing = 11.86 in | Clear cover = 1.06 in |
| Confinement: Other | phi(a) = 0.9, phi(b) = 0.9, phi(c) = 0.9 | | |

```
                                  OOOOO
                                 OO   OO
                                 OO   OO
OOOOOOO    OOOOO   OOOOO   OO        OOOOO   OO    OO   OO   OOOOOOOO    OOOO
OO    OO  OO      OO   OO  OO       OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OO    OO  OO      OOOOOOO  OO   OO  OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OOOOOOO   OO      OO   OO  OO   OO  OO   OO  OO    OO   OO  OO   OO  OO  OO   OO
OO         OOOOO  OO   OO   OOOOO    OOOOO   OOOOO  OOOOO   OO   OO  OO  OO   OO (TM)
```

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pcaColumn v4.10 (TM)
Computer program for the Strength Design of Reinforced Concrete Sections
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## General Information:

File Name: C:\Documents and Settings\brg_rjb\Desktop\cline1.col
Project: Cline
Column: Engineer: RJB
Code: ACI 318-02 Units: English

Run Option: Investigation Slenderness: Not considered
Run Axis: Y-axis Column Type: Structural

## Material Properties:

f'c = 5 ksi fy = 60 ksi
Ec = 4030.51 ksi Es = 29000 ksi
Ultimate strain = 0.003 in/in
Beta1 = 0.8

## Section:

Rectangular: Width = 15 in Depth = 12 in

Gross section area, Ag = 180 in^2
Ix = 2160 in^4 Iy = 3375 in^4
Xo = 0 in Yo = 0 in

## Reinforcement:

Bar Set: ASTM A615

| Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) | Size | Diam (in) | Area (in^2) |
|---|---|---|---|---|---|---|---|---|
| # 3 | 0.38 | 0.11 | # 4 | 0.50 | 0.20 | # 5 | 0.63 | 0.31 |
| # 6 | 0.75 | 0.44 | # 7 | 0.88 | 0.60 | # 8 | 1.00 | 0.79 |
| # 9 | 1.13 | 1.00 | # 10 | 1.27 | 1.27 | # 11 | 1.41 | 1.56 |
| # 14 | 1.69 | 2.25 | # 18 | 2.26 | 4.00 | | | |

Confinement: Other; #3 ties with #10 bars, #4 with larger bars.
phi(a) = 0.9, phi(b) = 0.9, phi(c) = 0.9

Pattern: Irregular

Total steel area, As = 0.41 in^2 at 0.23% (Note: rho < 0.50%)

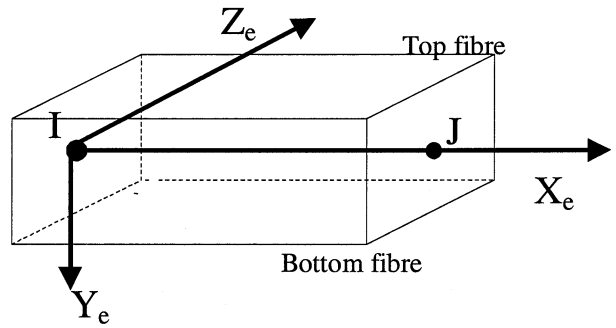
| Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) | Area in^2 | X (in) | Y (in) |
|---|---|---|---|---|---|---|---|---|
| 0.21 | -6.2 | 0.0 | 0.21 | 6.2 | 0.0 | | | |

## Control Points:

| Bending about | Axial Load P kip | X-Moment k-ft | Y-Moment k-ft | N.A. depth in | eps_t | Phi |
|---|---|---|---|---|---|---|
| Y @ Max compression | 709.3 | -0.00 | -0.00 | 44.10 | -0.00207 | 0.900 |
| @ Allowable comp. | 638.3 | 0.00 | 39.85 | 17.02 | -0.00059 | 0.900 |
| @ fs = 0.0 | 513.0 | 0.00 | 90.17 | 13.69 | 0.00000 | 0.900 |
| @ fs = 0.5*fy | 378.5 | 0.00 | 115.03 | 10.18 | 0.00103 | 0.900 |
| @ Balanced point | 296.7 | 0.00 | 116.71 | 8.10 | 0.00207 | 0.900 |
| @ Tension Control | 187.7 | 0.00 | 96.67 | 5.13 | 0.00500 | 0.900 |
| @ Pure bending | -0.0 | -0.00 | 13.52 | 0.61 | 0.06445 | 0.900 |
| @ Max tension | -22.4 | 0.00 | -0.00 | 0.00 | 9.99999 | 0.900 |
| -Y @ Max compression | 709.3 | 0.00 | -0.00 | 44.10 | -0.00207 | 0.900 |
| @ Allowable comp. | 638.3 | 0.00 | -39.85 | 17.02 | -0.00059 | 0.900 |
| @ fs = 0.0 | 513.0 | -0.00 | -90.17 | 13.69 | 0.00000 | 0.900 |
| @ fs = 0.5*fy | 378.5 | -0.00 | -115.03 | 10.18 | 0.00103 | 0.900 |
| @ Balanced point | 296.7 | -0.00 | -116.71 | 8.10 | 0.00207 | 0.900 |
| @ Tension Control | 187.7 | -0.00 | -96.67 | 5.13 | 0.00500 | 0.900 |
| @ Pure bending | -0.0 | -0.00 | -13.52 | 0.61 | 0.06445 | 0.900 |
| @ Max tension | -22.4 | 0.00 | -0.00 | 0.00 | 9.99999 | 0.900 |

## 3.2 THE LOCAL COORDINATE SYSTEM (Xe, Ye, Ze)

This system is used for the fixation of the orientation of displacements and section forces in segments.




The positive Xe-axis has its origin in end i of a segment

The Ze-axis is parallel to the global Z-axis.

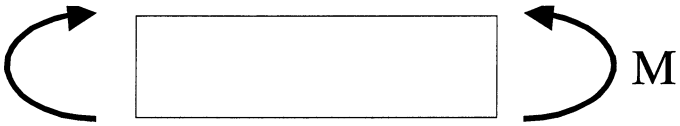
The orientation of the Ye-axis is as shown.

The centre of gravity for a segment is indicated at the section ends

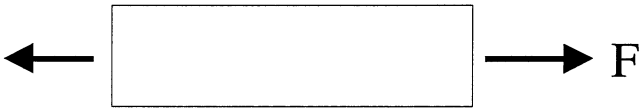
Axial forces are parallel to Xe-axis, shear forces are parallel to the Ye-axis and bending moments are about the Ze-axis.

The top fibre of a segment intersects the negative Ye-axis and the bottom fibre intersects the positive Ye-axis. Hence it follows that node I must be the node with the smaller value and node J the node with the larger value of the X-coordinate.

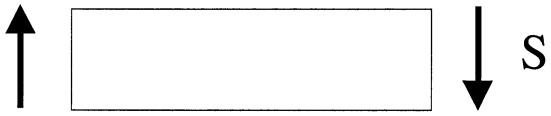
8.4/55




Moment




Axial Force




Shear Force

Patricia,

I understand that you are confused by the results of Brug.

In your model in program Brug Web 1 is defined from node 2 to 3 and Web 2 from node 4 to 5.

According to the beam- notation rules a positive moment gives a positive stress at the bottom of the beam.

In this model it means that if Web 1 is loaded by a positive moment there is a tensile stress on the outside of the box girder and Web 2 with the same positive moment a tensile stress on the inside of the box girder.

Jaap
10 / 7 /08

# 8.5 Review of Longitudinal Shear Analysis (MathCad Analysis)

## 8.5 Review of Longitudinal Shear Analysis (MATHCAD Analysis)

8.5/2

**URS**

Project: Cline --Seg 6 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk R J B

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File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 6 EB\

Node := 121 Position := Back $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = 874 \cdot kips$ | $M_{dc_x} = -23 \cdot kip \cdot ft$ | $T_{dc_x} = -73 ft \cdot kips$ | $N_{dc_x} = 1 \cdot kips$ | Dead Load |
| $V_{dw_x} = 105 \cdot kips$ | $M_{dw_x} = 14 \cdot kip \cdot ft$ | $T_{dw_x} = 101 \cdot kip \cdot ft$ | $N_{dw_x} = 1 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = 117 \cdot kips$ | $M_{psec_x} = 0 \cdot kip \cdot ft$ | $T_{psec_x} = -688 \cdot kip \cdot ft$ | $N_{psec_x} = 0 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = -108 kip$ | $M_{crsh_x} = -160 \cdot kip \cdot ft$ | $T_{crsh_x} = -911 \cdot kip \cdot ft$ | $N_{crsh_x} = 97 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 633 \cdot kips$ | $M_{LLvmax_x} = -259 \cdot kip \cdot ft$ | $T_{LLvmax_x} = 3356 \cdot kip \cdot ft$ | $N_{LLvmax_x} = -3 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -153 \cdot kips$ | $M_{LLvmin_x} = 132 \cdot kip \cdot ft$ | $T_{LLvmin_x} = -1584 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 2 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = 585 \cdot kips$ | $M_{LLtmax_x} = -268 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 3723 \cdot kip \cdot ft$ | $N_{LLtmax_x} = -2 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = -70 \cdot kips$ | $M_{LLtmin_x} = 149 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -1932 \cdot kip \cdot ft$ | $N_{LLtmin_x} = 2 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = -1175 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10777 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 25 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1226 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = 92 \cdot kips$

$M_{tu_x} = -139 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = 4679 \cdot kip \cdot ft$

$N_{tu_x} = 46 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

N to verify

$A_{box_x} = 13174 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 40905 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$(0.31)(12/10) = 0.372\ in^2/ft$

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 67.433 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web (adjust for ducts in web) ?

BRUG Analysis

$A_{b_x} = 0.271 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

BRUS

$A_{bs_x} = 0.257 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 0 \cdot in^2$ Area of Post-Tensioning Steel ?

$d_{t_x} = 101 \cdot in$ Depth for Torsion

$A_{s_x} = 9.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 106 \cdot in$ Depth of Mild Steel

Zero out for Flexure L.R.
Conservative for Shear

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

Strength II ?

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = 2168 \cdot kips$ | $T_{uvmax_x} = 3447 \cdot kip \cdot ft$ | $M_{uvmax_x} = -437\, ft \cdot kips$ | $N_{uvmax_x} = 47 \cdot kips$ |
| $V_{uvmin_x} = 1106 \cdot kips$ | $T_{uvmin_x} = -3222 \cdot kip \cdot ft$ | $M_{uvmin_x} = 90\, ft \cdot kips$ | $N_{uvmin_x} = 54 \cdot kips$ |
| $V_{utmax_x} = 2103 \cdot kips$ | $T_{utmax_x} = 3943 \cdot kip \cdot ft$ | $M_{utmax_x} = -450\, ft \cdot kips$ | $N_{utmax_x} = 49 \cdot kips$ |
| $V_{utmin_x} = 1219 \cdot kips$ | $T_{utmin_x} = -3691 \cdot kip \cdot ft$ | $M_{utmin_x} = 113\, ft \cdot kips$ | $N_{utmin_x} = 54 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

(5.8.3.4.3)

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.725\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$ (pg 5-75)

(5.8.6.3)

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 10598 \cdot kip \cdot ft$

(5.8.2.9)

$$d_{e_y} := \frac{\max\left(\overset{67.4}{y_{bot_y}} - \dfrac{M_{prim_y}}{N_{prim_y}}, \overset{108-67.4}{H_{box_y} - y_{bot_y}} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 106 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 95.4 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

(5.8.3.4.1)

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - \overset{0}{\cancel{A_{ps_i}}} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \text{ if } \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \text{ otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = 0.00401$

**URS**

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Job ____ Project No. ____ Sheet ____ of ____

Description Cline Computed by RJB Date 8/19/09

Checked by ____ Date ____

Reference

$$f_{pc} = \frac{N_{prim}}{A_{box}} + \frac{N_{ptlo}}{A_{box}} + \frac{N_{psec}}{A_{box}} + \frac{N_{ptls}}{A_{box}}$$

$$f_{pc} = \frac{\overset{-0.818}{-10777\ k}}{13174} + \frac{\overset{0.093}{1226}}{13174} + 0 + 0 = \underline{-0.725}$$

$$k = \sqrt{1 - \frac{f_{pc}}{0.0632\sqrt{f'_c}}} = \sqrt{1 + \frac{0.725}{0.0632\sqrt{5}}} = 2.48 \leq 2$$

$\underline{k = 2}$

$$T_{cr} = 0.0632\ k\sqrt{f'_c}\ 2\ A_o\ b_e$$

$$T_{cr} = 0.0632\ (2)\sqrt{5}\ (2)(40905)(5.5'') = 127{,}174.8\ k\text{-in}$$

$\underline{10598\ k\text{-ft}}$

$$d_e = \frac{\overset{0}{A_{ps}}\ f_{ps}\ d + A_s f_y d_s}{\underset{0}{A_{ps}}\ f_{ps} + A_s f_y} = \frac{(9.2\ in^2)(60\ ksi)(106)}{(9.2)(60)} = 106$$

$0.9\ d_e = 0.9(106) = \underline{95.4\ in.}$ ← $0.72h = 77.8''$ ?

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$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps} f_{po}\right)}{E_s A_s + E_p A_{ps}}$$

$$\varepsilon_s = \frac{\overset{54.97\ k}{\frac{437 \times 12}{95.4}} + \overset{23.5\ k}{0.5(47)} + \overset{993\ k}{|2168 - 1175|} - 0}{\underbrace{(29000)(9.2\ in^2)}_{266800}}$$

$\varepsilon_s = \underline{0.00402}$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 43.052 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 1.197$

Adjust for ducts in web?

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 120.999 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"Yes"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 453.715\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 351.97 \cdot kips$

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$$\theta = 29 + 3500\,\varepsilon_s = 29 + 3500(0.00402) = 43.07^\circ$$

$$\beta = \frac{4.8}{1 + 750\,\varepsilon_s} = \frac{4.8}{1 + 750(0.00402)} = 1.1955$$

$$V_c = 0.0316\,\beta\sqrt{f'_c}\,b_v d_v$$

$$V_c = 0.0316(1.1955)\sqrt{5}\,(15'')(95.4'')$$

$$V_c = \underline{120.88\,k}$$

$T_{cr} = 10598$ k-ft

$$\frac{1}{3}\phi T_{cr} = \frac{1}{3}(0.9)(10598)$$

$$= 3179\ k\text{-ft} < 3447\ k\text{-ft}$$

$T_{uvmax}$

∴ Consider Torsion

$$V_d = \frac{\overbrace{216.8k - 1.35(633)}^{437.8}}{3} + \frac{(3447 - 1.35(3356))\,101''}{2(40905)} = \underline{453.85}$$

+16.05

$$V_{LL} = \frac{\overbrace{1.35(633)}^{284.9}}{3} + \frac{1.35\,(\overset{671}{3356})(101)}{2(40905)} = \underline{351.97}$$

×12

$RF_{vpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$RF$

$RF_{vpos_{x,1}} = 0.993$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$\varepsilon_{svmin} :=$ for $i \in y$

90 x 12

$$\varepsilon_1 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{95 \cdot d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

0.5(54) 1106 − 1175 0

29000 (9.2)

$$\varepsilon_2 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$\varepsilon$

$\varepsilon_{svmin_x} = 0.0004$

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$$V_s = \frac{2\,A_v\,f_y\,d_v}{s\,\tan(\theta)} = \frac{2(0.372)(60\text{ ksi})(95.4'')}{12\tan 43.07^\circ}$$

$$V_s = \underline{379.64\text{ k}}$$

$$V_p = \underline{1175\text{ k}}$$

$$V_c = \underline{120.9\text{ k}}$$

$$\phi V_n = 0.9\left(120.9 + 379.6 + \frac{1175}{3}\right) = \underline{802.95\text{ k}}$$

$$RF_1 = \frac{802.95 - 453.85}{351.97} = \underline{0.992}$$

$$RF_2 = \frac{\overbrace{0.372 - 0.134}^{0.238}}{\underbrace{0.271 - 0.134}_{0.137}} = \underline{1.74}$$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 30.402 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 3.691$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 373.197 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"Yes"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 421.619\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -100.53 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmin_i})}$ 604.8

$V_p \leftarrow |V_{prim_i}|$ 391.7 1175

$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$ 373.2 + 604.8 3 1232.7

$RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$ 1232.7 421.6 100.5 = 8.07

$RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$ = 1.74

$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$

$RF_{i,2} \leftarrow RF_{1_i}$

$RF_{i,3} \leftarrow RF_{2_i}$

RF

$RF_{vneg_{x,1}} = 1.737$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$\varepsilon_{stmax} :=$ for $i \in y$

$\varepsilon_1 \leftarrow \dfrac{\left( \dfrac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| |V_{utmax_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$

$\varepsilon_2 \leftarrow \dfrac{\left( \dfrac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| |V_{utmax_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$

$\varepsilon_i \leftarrow \varepsilon_1$ if $\varepsilon_1 \geq 0$

$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004)$ otherwise

$\varepsilon$

$\varepsilon_{stmax_x} = 0.00378$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 42.231 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 1.252$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 126.551 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 453.715\,kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 337.71 \cdot kips$

$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$RF_{tpos_{x,1}} = 1.079$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{stmin_x} = 0.00032$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 30.112 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 3.877$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 391.975 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebtmin_x} = 421.619\,kip$

$$V_{LLwebtmin_y} := \frac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebtmin_x} = -70.14 \cdot kips$

$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.737}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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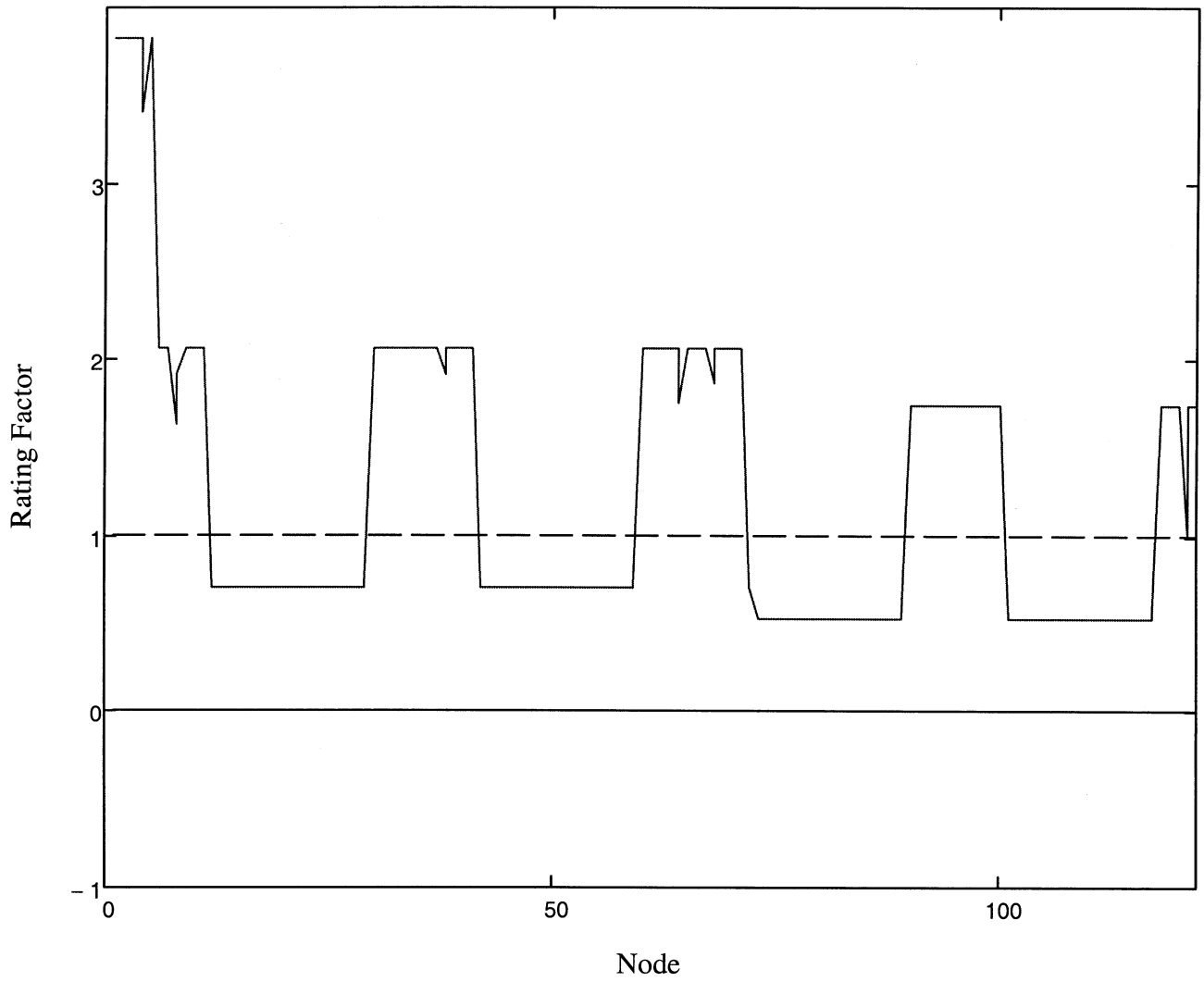
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— – Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.993$ at node $minRF_2 = 121$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.528$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

Based on 14"

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$V_{p_x} = -391.667\,kip$ Based on 14" web

$V_{prim_x} = -1.175 \times 10^3\,kip$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ 193.4 $m_{r_x} = 178.893 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ 96.2 $m_{rd_x} = 89.239 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$

$\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ Ab (0.271) $b_{1_x} = 0.319 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ Abd (0.134) $b_{1d_x} = 0.158 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ ← should be based on $A_v = 0.372$

$b_1 = \frac{(0.372)(60)}{0.85(5)(12")}$

$b_1 = 0.438"$

13.469 $y_{1_x} = 13.528 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.646 \cdot kip \cdot ft$ 22.55

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$d_y = 15 - 1 - 0.625 = 13.375''$

$b = 12''$

$$M_r = \phi(A)(f_y)\left(d - \frac{A_b f_y}{2(0.85)(f'_c)(b)}\right)$$

$$M_r = (0.9)(0.271)(60)\left(13.375 - \frac{\overbrace{(0.271)(60)}^{0.13941}}{2(0.85)(5)(12'')}\right)$$

$M_r = \underline{193.4 \text{ k-in}} = \underline{16.1 \text{ k-ft}}$

$$M_{rd} = (0.9)(0.134)(60)\left(13.375 - \frac{(0.134)(60)}{2(0.85)(5)(12'')}\right)$$

$M_{rd} = \underline{96.2 \text{ k-in}} = \underline{8.0 \text{ k-ft}}$

$b_o = 15 - 2 - 0.625 = \underline{12.375''}$

$b = 1 + \frac{0.625}{2} = \underline{1.3125''}$

$y_1 = 12.375 + 1.3125 - \frac{0.438''}{2} = \underline{13.469''}$

$\phi = (0.9)(0.372)(60)(13.469'') = \underline{270.57 \text{ k-in}} = \underline{22.55 \text{ k-ft}}$

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$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 189.939 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 632.345 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad \overbrace{\dfrac{(189.939)(12)}{95.4 \cos 43.052}}^{22.32\,k}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = \cancel{604.834} \cdot kips$ $\quad 1233 \times 10^3$

Vcvmin ?

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.006 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 1.394 \cdot in$ $\quad 0.875''$

θvmin ?

23.6

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.646 \cdot kip \cdot ft$ $\quad 22.55$

Derive the Interaction Diagram:

$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad V_{n_i} \leftarrow \phi V_{n_i} \\ \quad V_{n_{7-i}} \leftarrow \phi V \\ V_n \end{array} \right.$ $\quad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad M_{n_i} \leftarrow \phi M_{n_i} \\ \quad M_{n_{7-i}} \leftarrow -\phi M_n \\ M_n \end{array} \right.$ $\quad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad M_{u_i} \leftarrow m_{rd_x} \\ \quad M_{u_{i+1}} \leftarrow m_{r_x} \\ M_u \end{array} \right.$ $\quad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad V_{u_i} \leftarrow \left|V_d\right| \\ \quad V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \\ V_u \end{array} \right.$

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Case II

$B_r = A_v f_y = (0.372\ in^2)(60\ ksi) = 22.32\ k$

$$V_s = \frac{A_v f_y d \cot(\theta)}{S} = \frac{(0.372)(60\ ksi)(95.4)\cot 43.052}{12''}$$

$V_s = \underline{189.939\ k}$

$\phi V_n = \phi\,(V_c + V_s + |V_{py}|)$

$$\phi V_n = 0.9\left(120.999 + 189.939 + \overbrace{\frac{1175}{3}}^{391.7}\right) = 632.3\ k$$

$$b_{req} = \frac{V_s}{0.85(F'_c)d_v \cot\theta} = \frac{189.939}{0.85(5)(95.4)\cot 43.052} = \underline{0.438''}$$

$$b = \frac{\overbrace{(0.372)(60)}^{22.32}}{0.85(5)(12)} = \underline{0.438''}$$

300.617

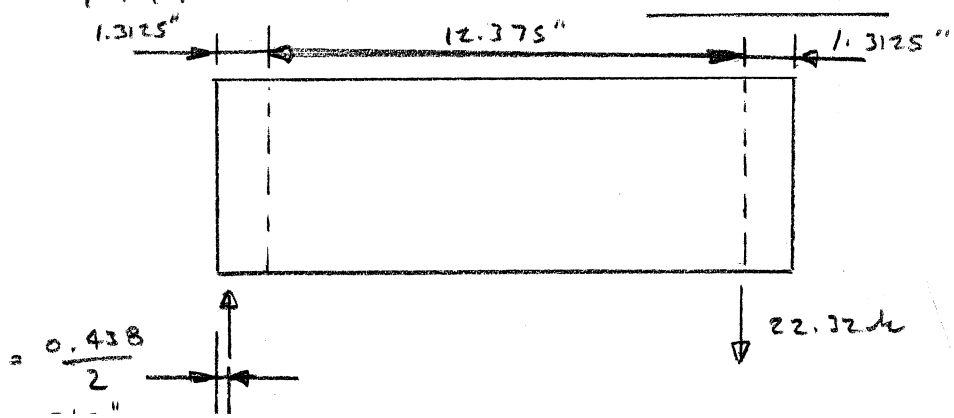
24.407 k-in

276.21

1.0935"

$$\phi M_n = 0.9\left[(0.372)(60\ ksi)(12.375'') - (22.32)\left(\frac{0.438}{2} - 1.3125\right)\right]$$

$\phi M_n = 270.56\ k\text{-}in = \underline{22.546\ k\text{-}in}$



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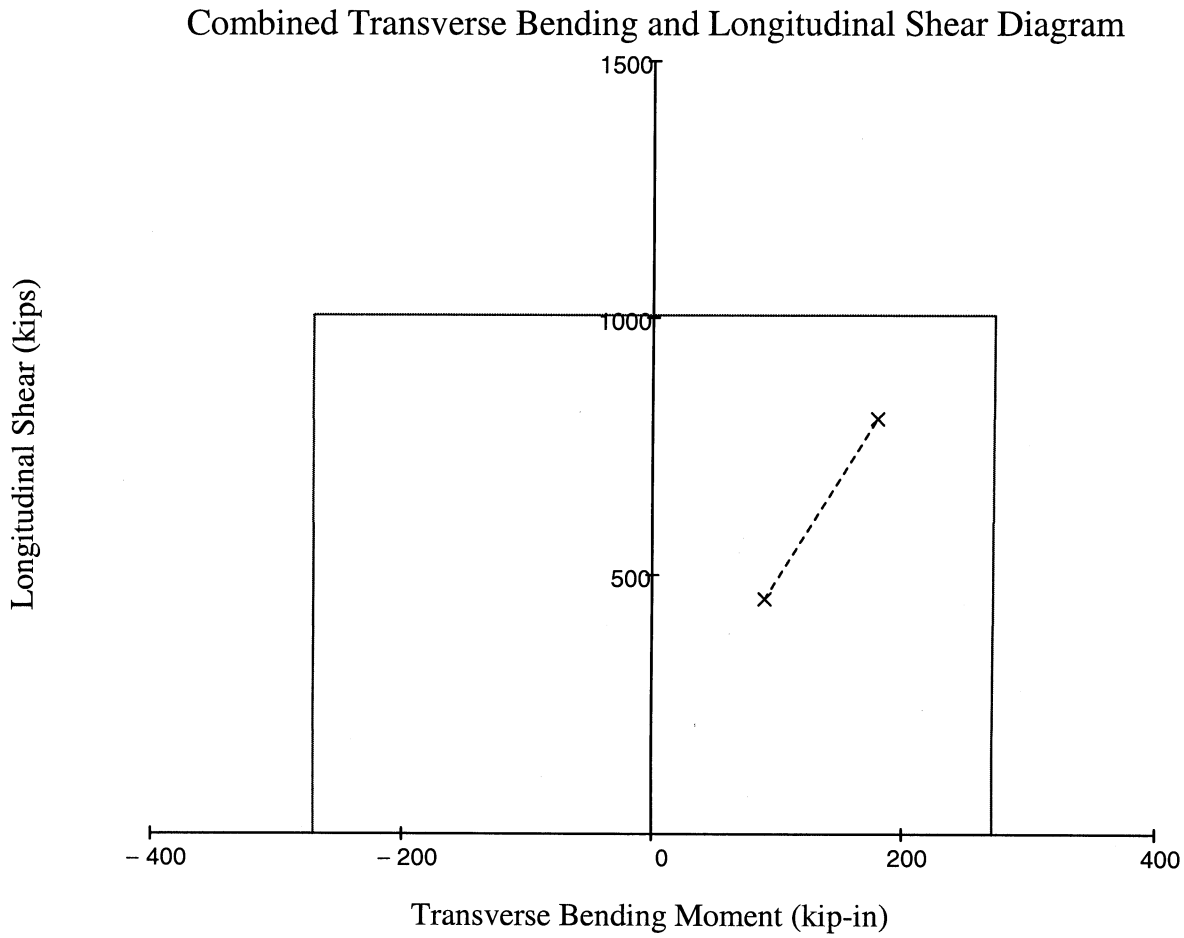


The interaction diagram above shows that the longitudinal shear ~~and transverse bending have not interaction~~ is not influenced by transverse bendin--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.036$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 1.568$ 0.993 1.737

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 1.635$ 1.079 1.737

Does not include worst case

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$$RF = \frac{\overbrace{271.75 - 89.239}^{182.51}}{\underbrace{178.893 - 89.239}} = 2.036$$

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Case III

$$V_s = \frac{2 \cdot A_v (f_y) d_v \cot \theta}{s}$$

$$V_s = \frac{2(0.372)(60)(95.4) \cot 30.402}{12}$$

$$V_s = \underline{604.8 \text{ k}}$$

$$\phi V_n = 0.9\left(\overset{120.999}{373.197} + 604.844 + \overset{391.7}{\frac{1175}{3}}\right) = \underline{1232.7 \text{ k}}$$

$$b = \frac{2(0.372)(60)}{0.85(5)(12)} = 0.875''$$

$$\phi M_n = 0.9\left[\overset{276.21}{(0.372)(60)(12.375)} - \overset{+39.06}{(44.64)\left(\frac{0.875}{2} - 1.3125\right)}\right]$$

$$\phi M_n = \underline{283.74 \text{ k-ft}} = \underline{23.6 \text{ k-ft}} > \underset{\phi M_n}{\underline{22.55}}$$

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Node := 36 Position := Ahead $b_{voverride}$ := 14

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = 1370 \cdot kips$ | $M_{dc_x} = -57826 \cdot kip \cdot ft$ | $T_{dc_x} = -600 ft \cdot kips$ | $N_{dc_x} = -15 \cdot kips$ | Dead Load |
| $V_{dw_x} = 108 \cdot kips$ | $M_{dw_x} = -1981 \cdot kip \cdot ft$ | $T_{dw_x} = -637 \cdot kip \cdot ft$ | $N_{dw_x} = -56 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = -234 \cdot kips$ | $M_{psec_x} = 29077 \cdot kip \cdot ft$ | $T_{psec_x} = 1228 \cdot kip \cdot ft$ | $N_{psec_x} = -1113 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = -22 kip$ | $M_{crsh_x} = 10644 \cdot kip \cdot ft$ | $T_{crsh_x} = 3139 \cdot kip \cdot ft$ | $N_{crsh_x} = -273 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 391 \cdot kips$ | $M_{LLvmax_x} = 2837 \cdot kip \cdot ft$ | $T_{LLvmax_x} = 1290 \cdot kip \cdot ft$ | $N_{LLvmax_x} = 54 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -76 \cdot kips$ | $M_{LLvmin_x} = 3686 \cdot kip \cdot ft$ | $T_{LLvmin_x} = 819 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 35 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = 215 \cdot kips$ | $M_{LLtmax_x} = 3685 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 1953 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 51 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = 62 \cdot kips$ | $M_{LLtmin_x} = -1015 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -1553 \cdot kip \cdot ft$ | $N_{LLtmin_x} = -209 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = -358 \cdot kips$ Primary PT Shear

$N_{prim_x} = -9234 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 10365 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 542 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = -75 \cdot kips$

$M_{tu_x} = 3710 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = 138 \cdot kip \cdot ft$

$N_{tu_x} = -218 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 9745 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 22218 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.232 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 124.188 \cdot in$ Height of Box

$y_{bot_x} = 84.787 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 11.95 \cdot in$ Width of Single Web

$A_{b_x} = 0.197 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.093 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.147 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.093 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 70.091 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 117 \cdot in$ Depth for Torsion

$A_{s_x} = 7.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 121.938 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = 2157 \cdot kips$ | $T_{uvmax_x} = 2834 \cdot kip \cdot ft$ | $M_{uvmax_x} = -37025\, ft \cdot kips$ | $N_{uvmax_x} = -1279 \cdot kips$ |
| $V_{uvmin_x} = 1527 \cdot kips$ | $T_{uvmin_x} = 2198 \cdot kip \cdot ft$ | $M_{uvmin_x} = -35879\, ft \cdot kips$ | $N_{uvmin_x} = -1305 \cdot kips$ |
| $V_{utmax_x} = 1920 \cdot kips$ | $T_{utmax_x} = 3729 \cdot kip \cdot ft$ | $M_{utmax_x} = -35880\, ft \cdot kips$ | $N_{utmax_x} = -1283 \cdot kips$ |
| $V_{utmin_x} = 1713 \cdot kips$ | $T_{utmin_x} = -1005 \cdot kip \cdot ft$ | $M_{utmin_x} = -42225\, ft \cdot kips$ | $N_{utmin_x} = -1634 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -1.006\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 5756 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \frac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \frac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 99.045 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 89.415 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00032$

$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.871 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.332$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 478.049 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"Yes"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 849.253\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 318.949 \cdot kips$

$$RF_{vpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$RF_{vpos_{x,1}} = 0.301$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$$\varepsilon_{svmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmin_x} = -0.00036$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.745 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.566$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 495.763 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"Yes"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 780.247\, kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_x} = -86.234 \cdot kips$

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$$RF_{vneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{vneg_{x,1}} = 1.338$$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| \left|V_{utmax_i}\right| - \left|V_{prim_i}\right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| \left|V_{utmax_i}\right| - \left|V_{prim_i}\right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{stmax_x} = -0.00034$$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.809 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.445$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 486.628 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 849.253\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 228.429 \cdot kips$

$$RF_{tpos} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{tmax_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{tpos_{x,1}} = 0.458$$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left( \frac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left( \frac{|M_{utmin_i}|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| |V_{utmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmin_x} = -0.00032$$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.883 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.31$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 476.421 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$\boxed{UseTorsionMinTorsion_x = \text{"No"}}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebtmin_x} = 814.75\,kip$

$$V_{LLwebtmin_y} := \frac{1.35\,V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebtmin_x} = 41.85 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.338}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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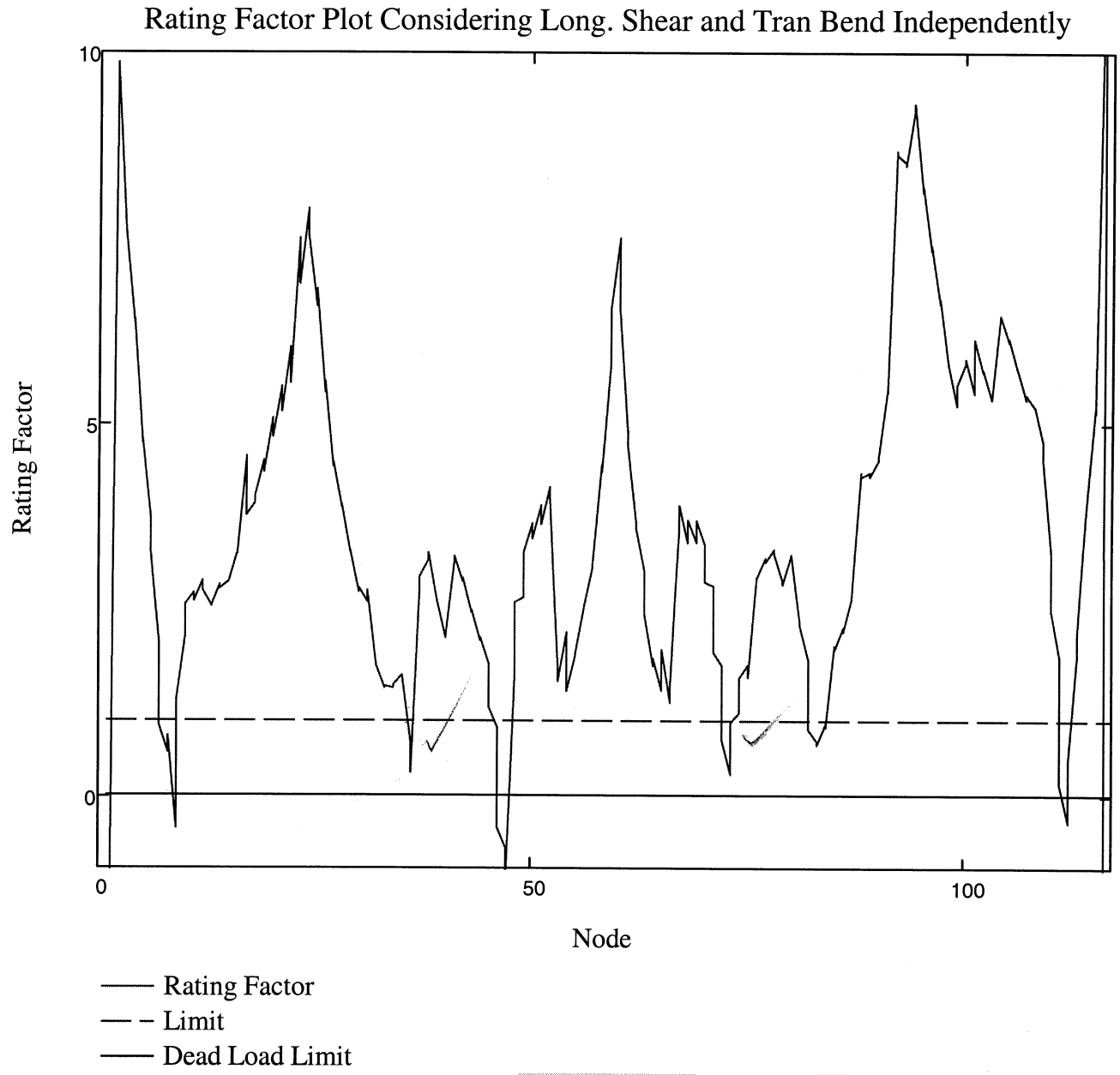


Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.301$ at node $minRF_2 = 36$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.418$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 130.544 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 61.806 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 9.325 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.232 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.109 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 10.521 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 13.95 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 11.008 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 13.95 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 196.558 \cdot kips$

$\phi V_{n2_y} := \phi \cdot (V_{cvmax_y} + V_{s2_y} + |V_{p_y}|)$ $\qquad \phi V_{n2_x} = 768.247 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.274 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 10.986 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 395.224 \cdot kips$

$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\qquad \phi V_{n_3} = 947.046 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.55 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 11.008 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_n \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow |V_d| \\ V_{u_{i+1}} \leftarrow |V_d + V_{LL}| \end{array} \right. \\ V_u \end{array} \right.$$

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Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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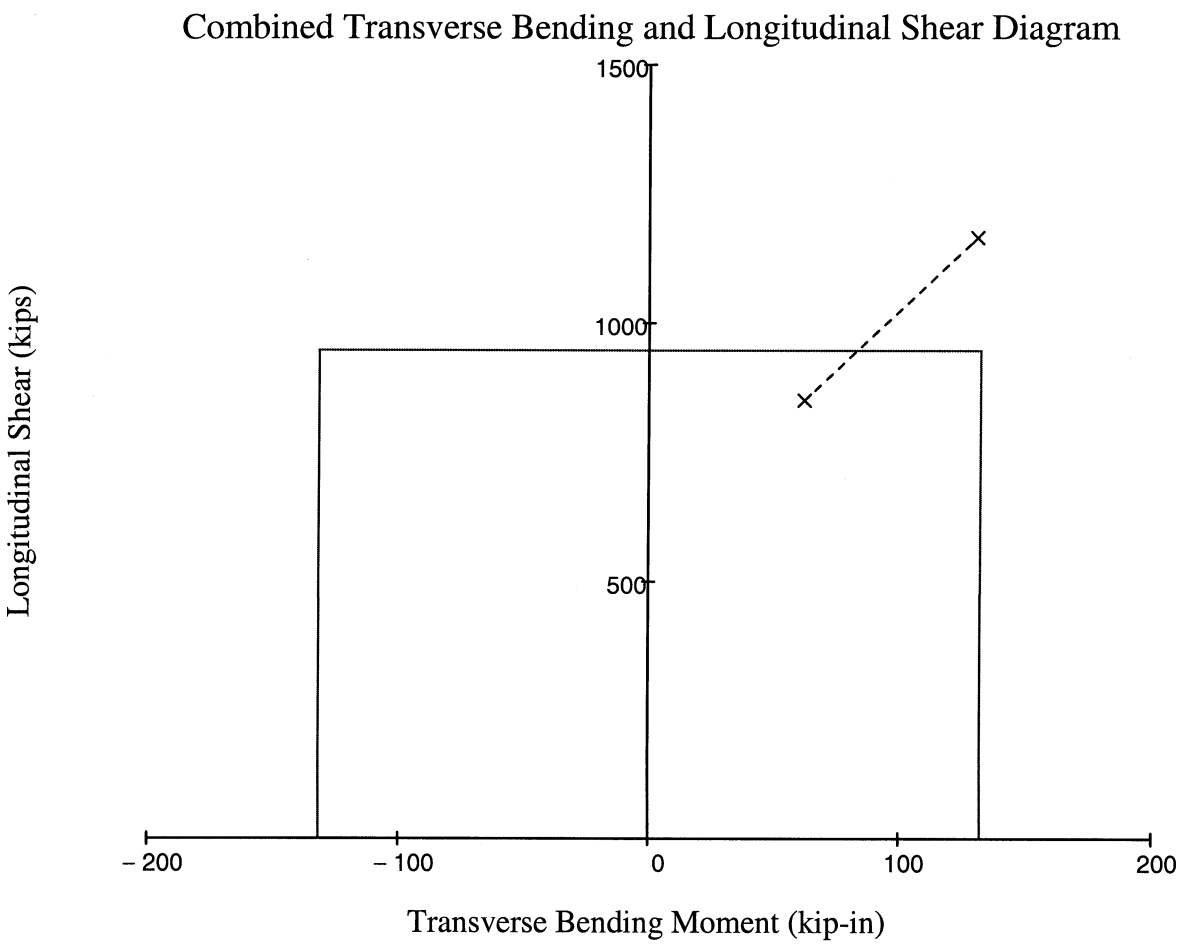


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 1.023$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 0.307$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 0.428$

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**URS**

Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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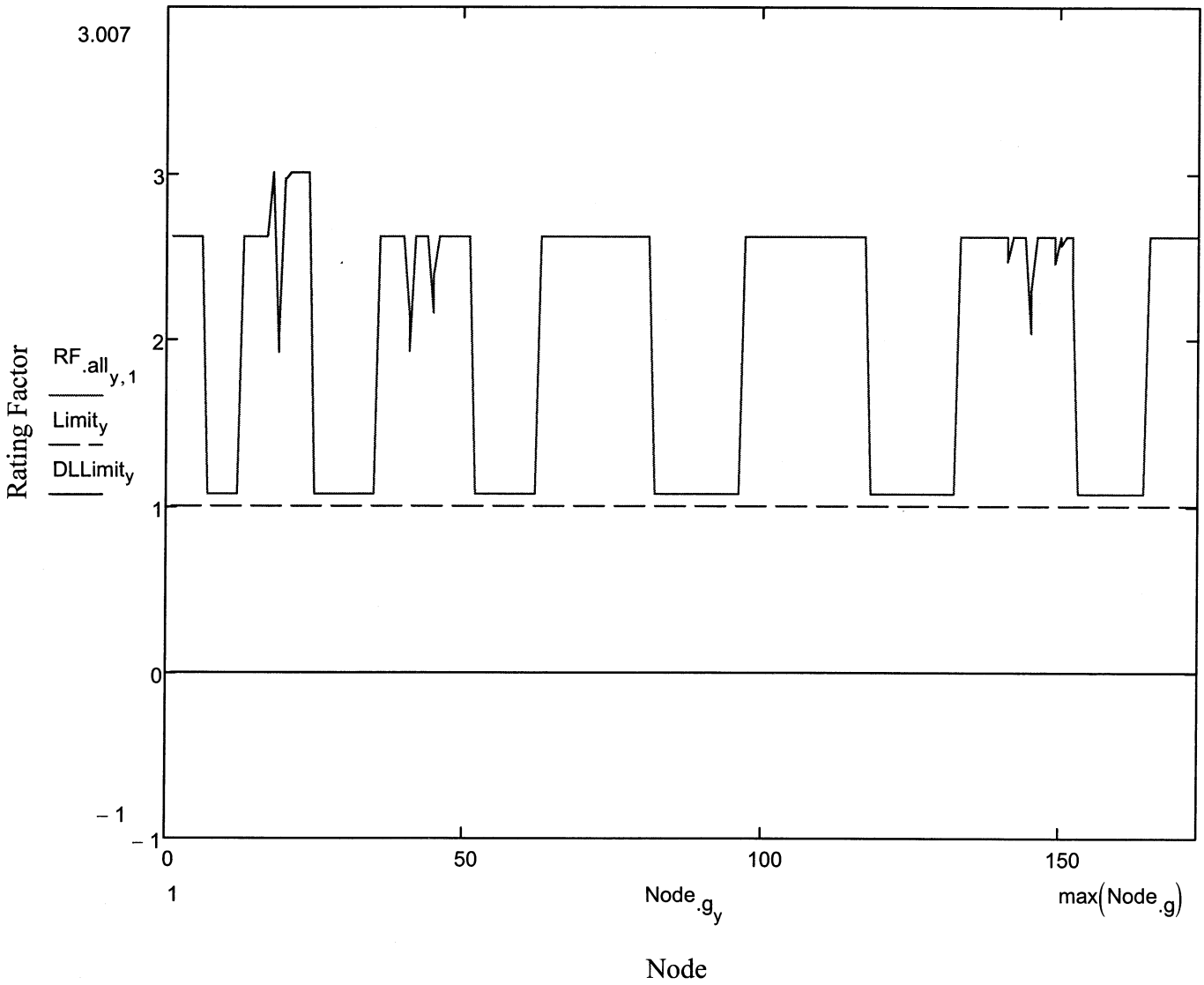
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.4$ at node $minRF_2 = 153$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 1 Gdr 2
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
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Date: 6 / 17 / 2009
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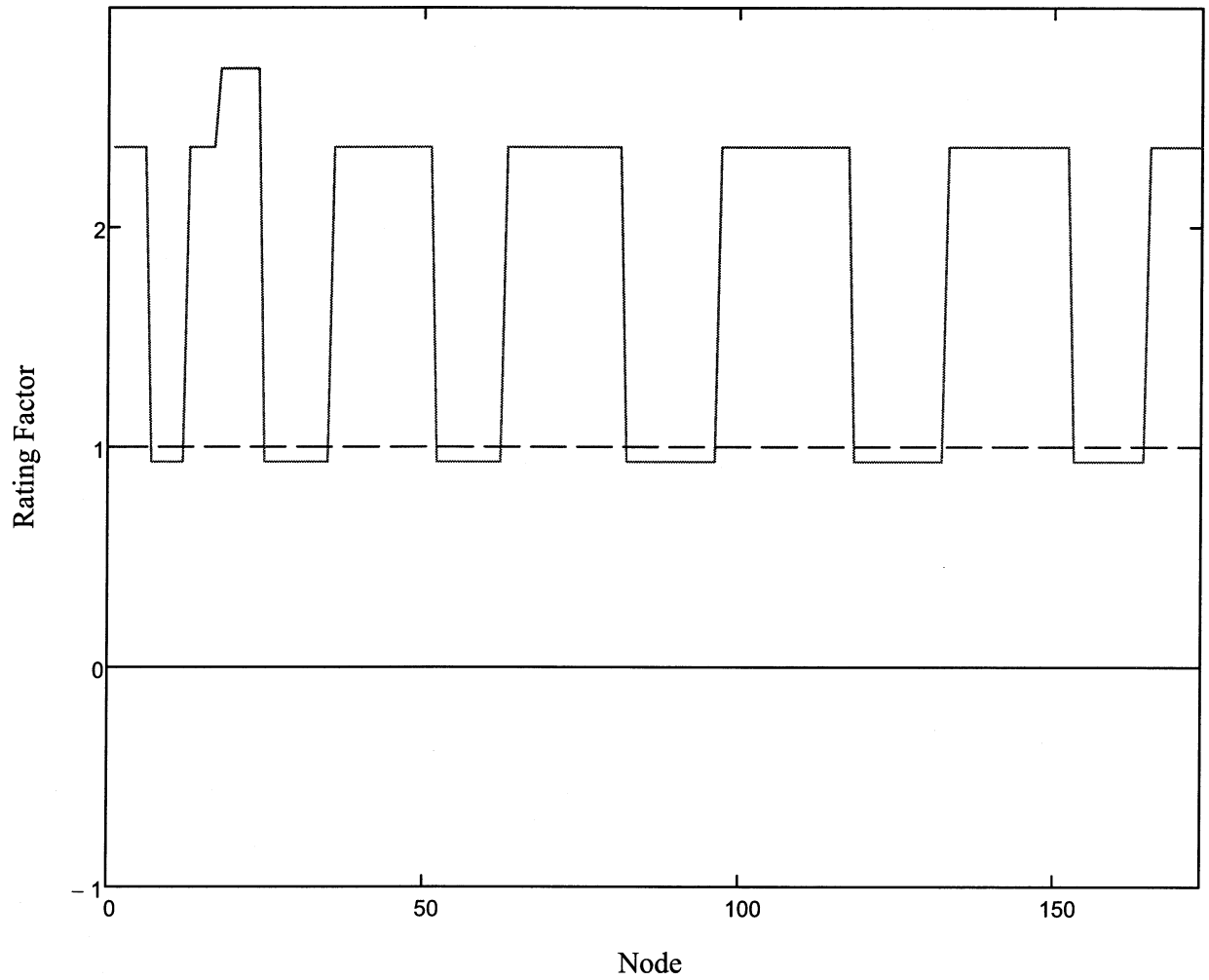
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.429$ at node $minRF_2 = 45$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Design: TSP
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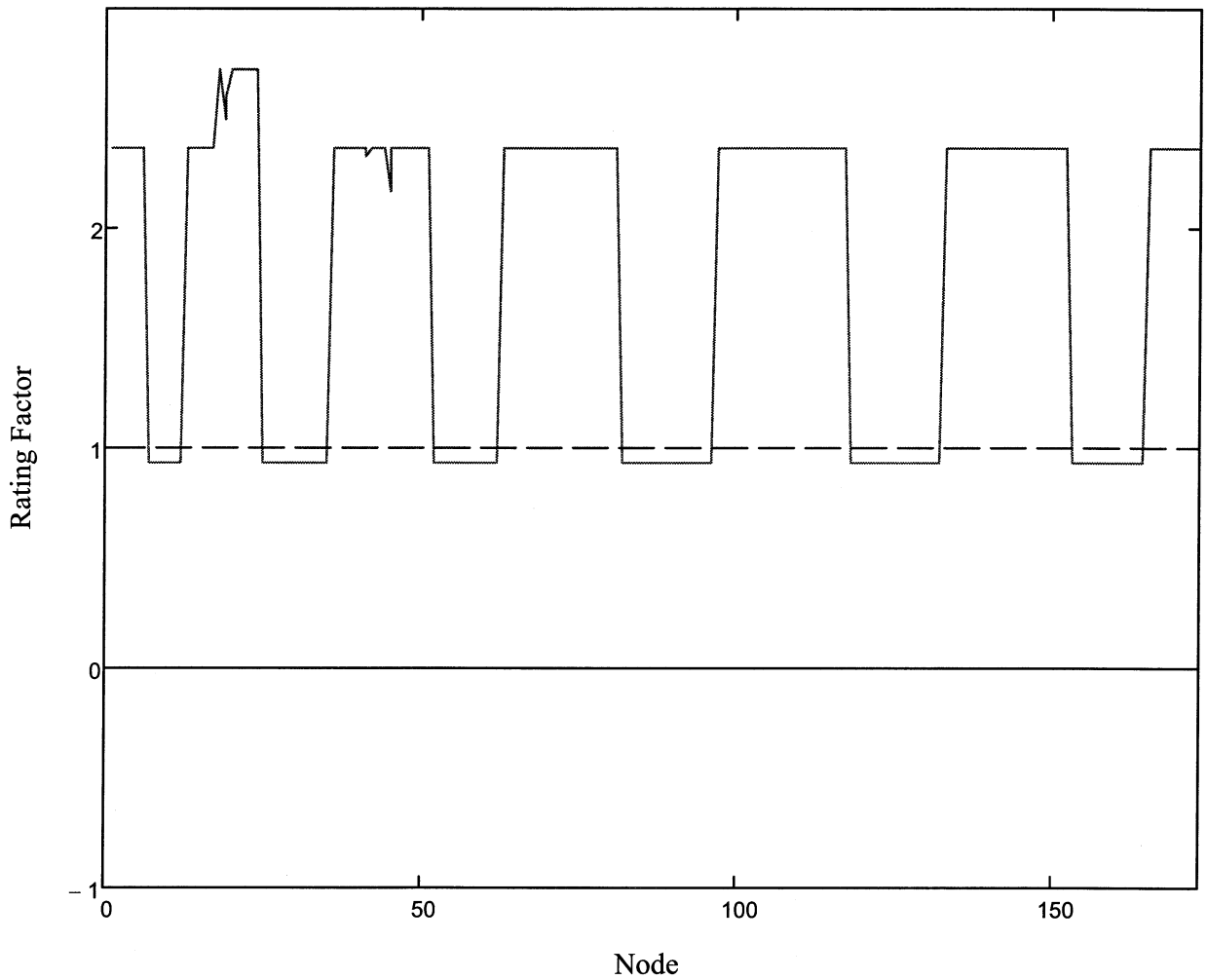
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.167$ at node $minRF_2 = 45$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 2 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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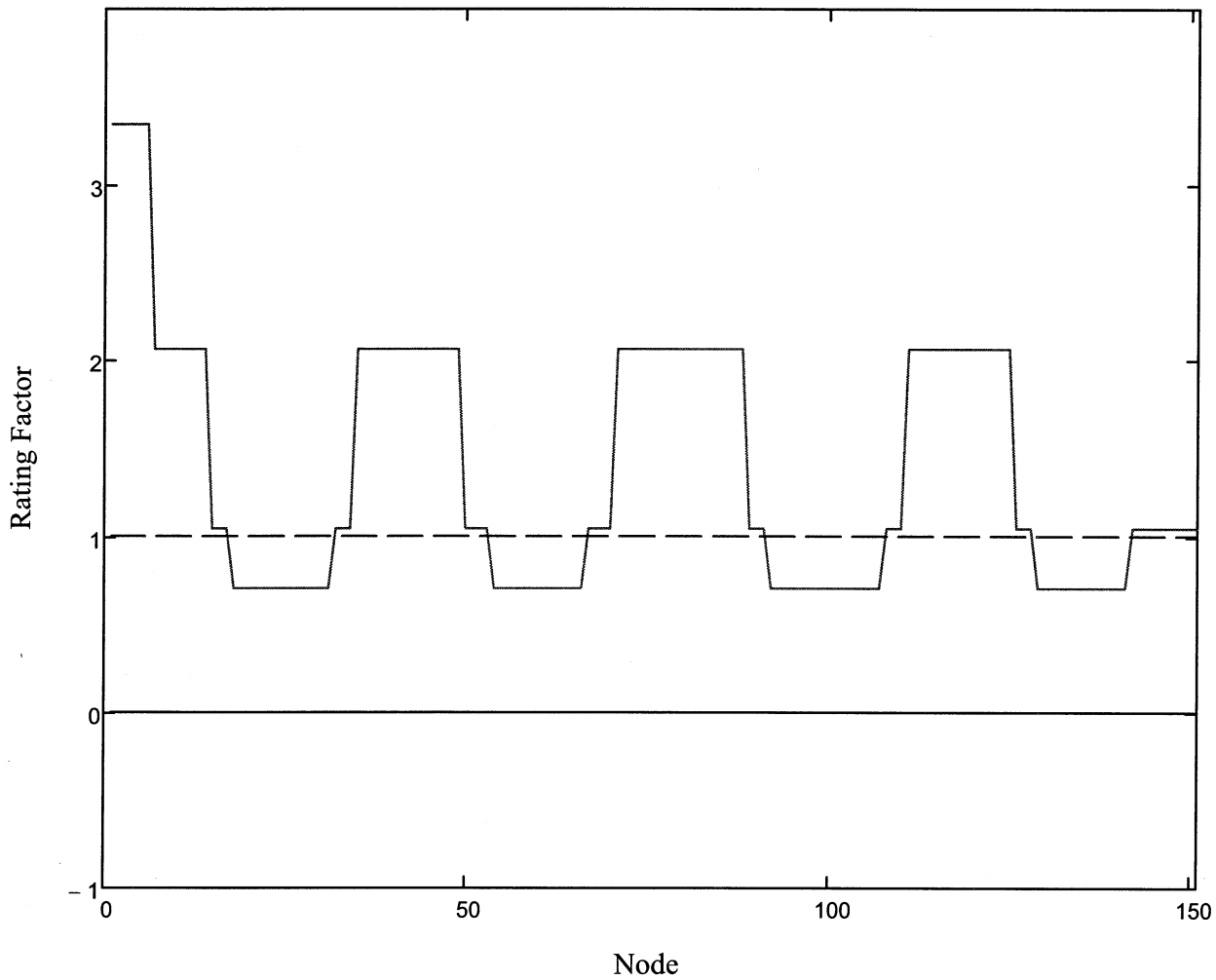
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.339$ at node $minRF_2 = 129$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 2 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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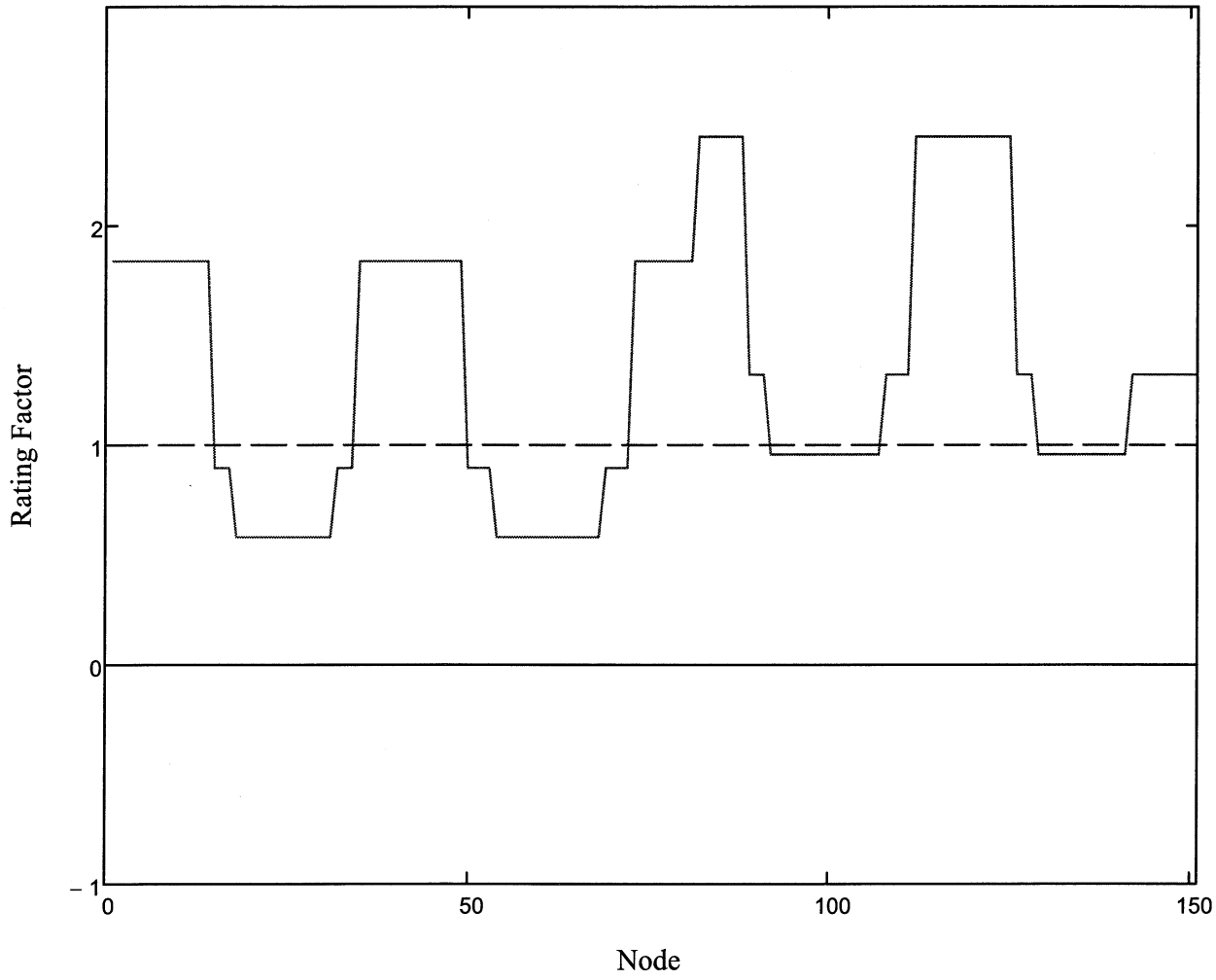
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.738$ at node $minRF_2 = 78$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 3 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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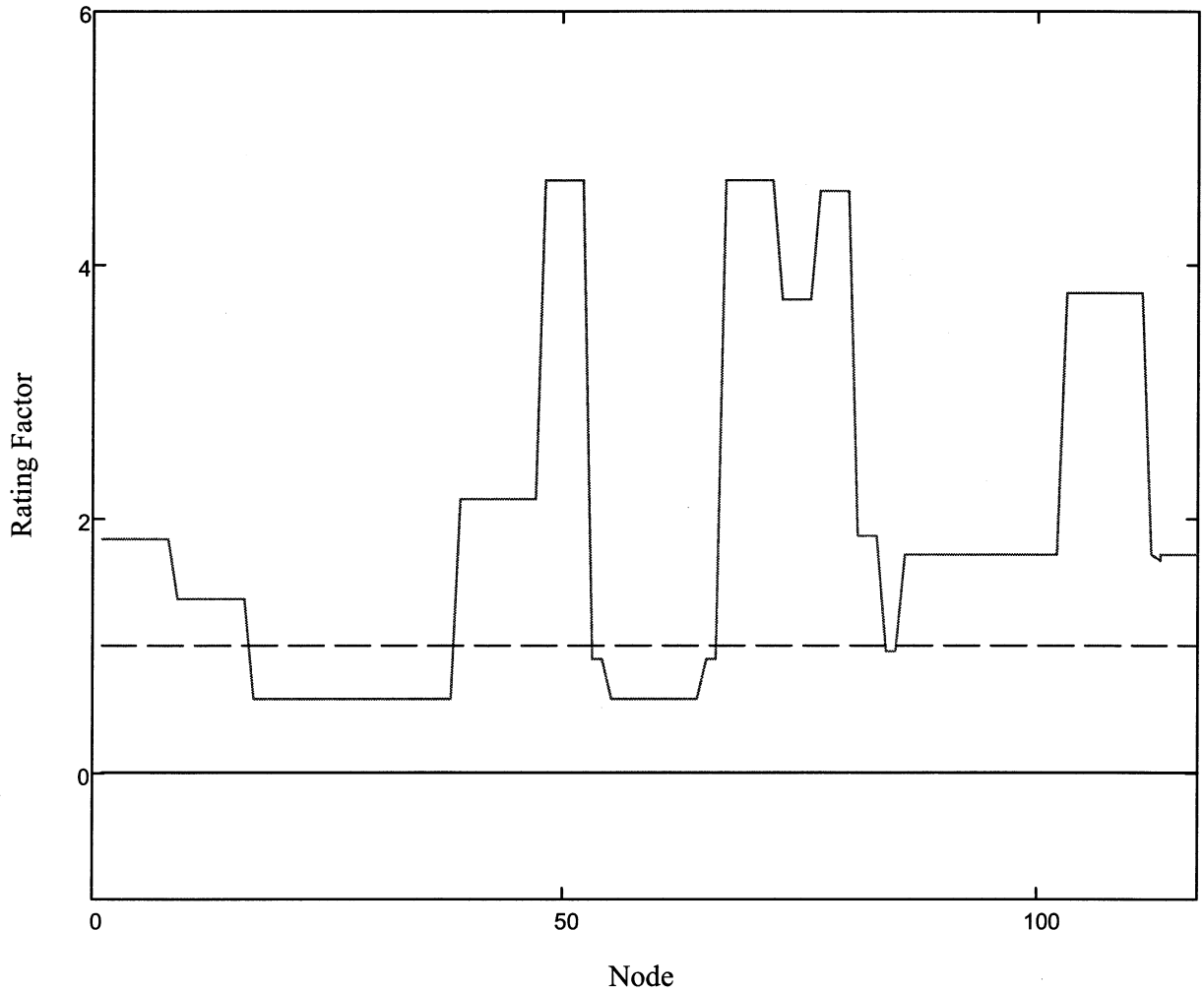
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.311$ at node $minRF_2 = 36$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

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URS

Project: Cline --Seg 3 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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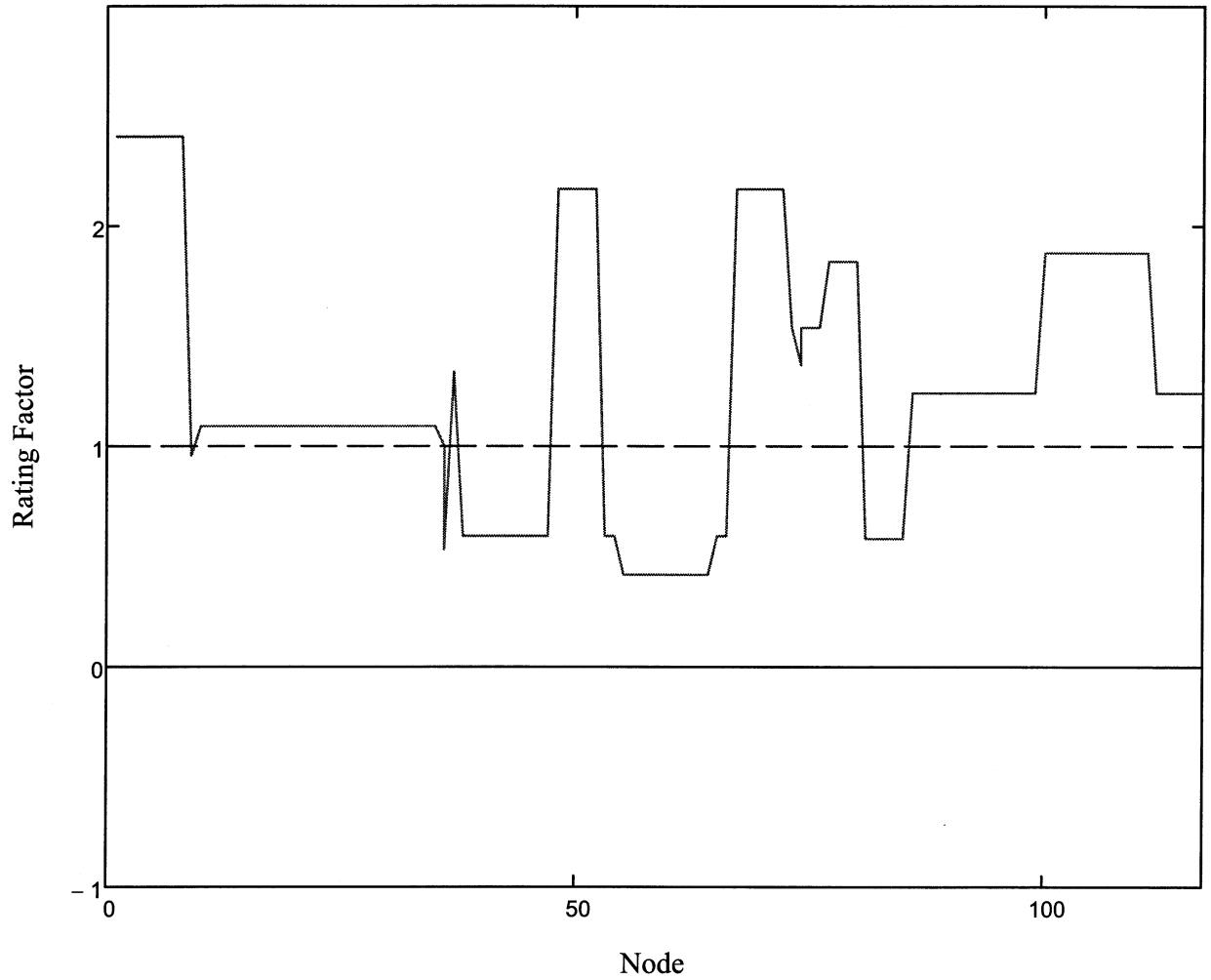
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.532$ at node $minRF_2 = 36$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 4 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Design: TSP
Check: Ind Chk

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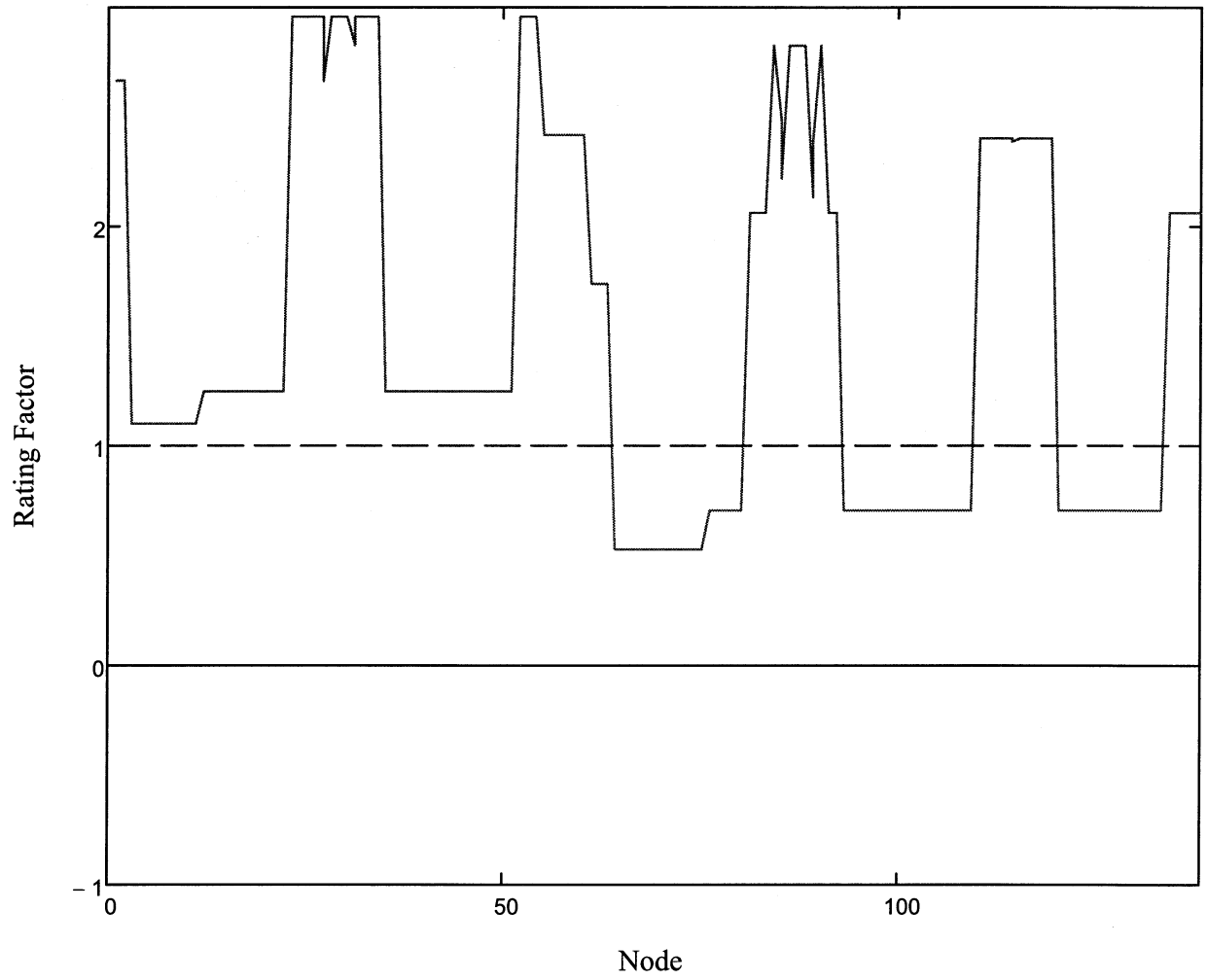
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.134$ at node $minRF_2 = 89$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 4 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Design: TSP
Check: Ind Chk

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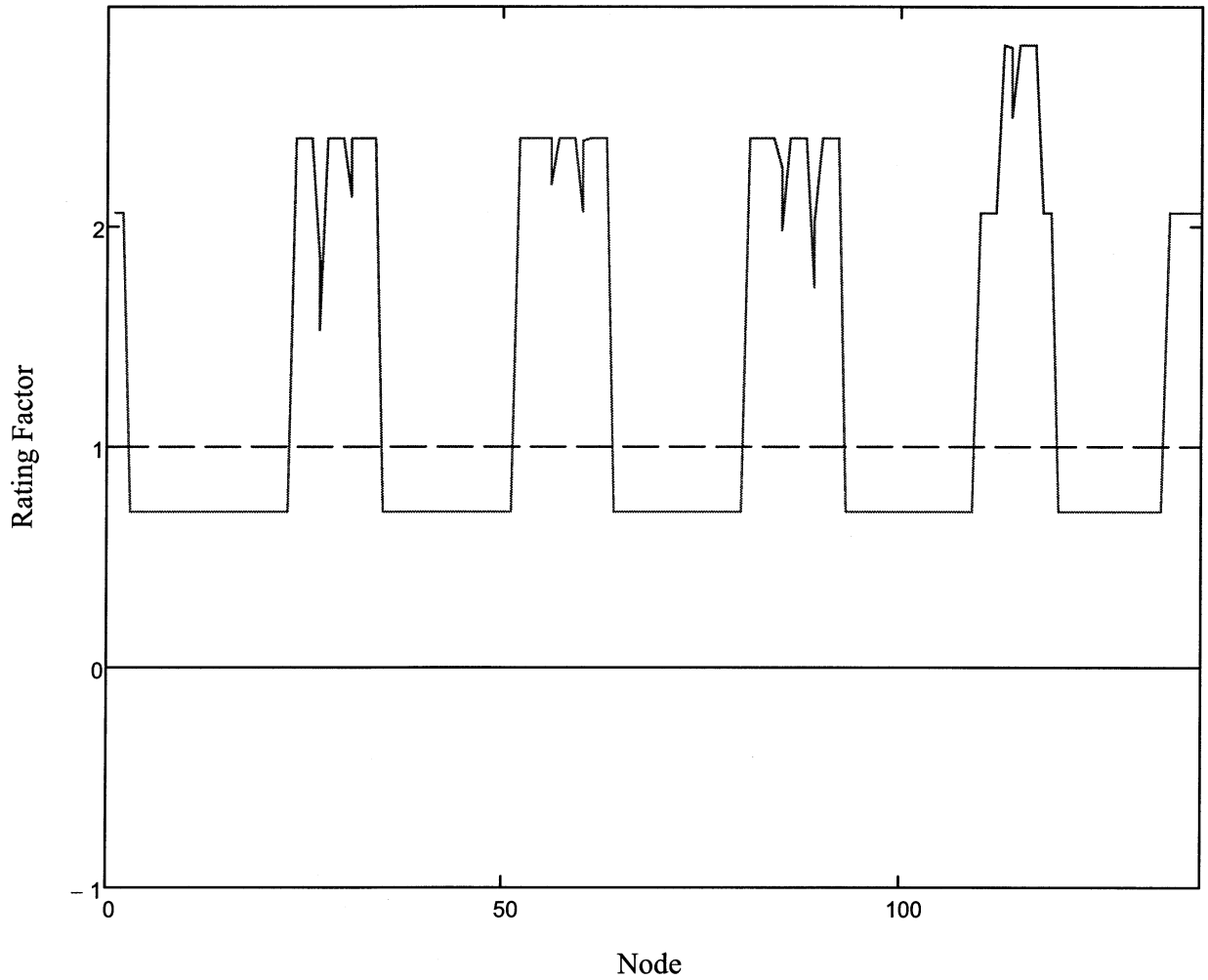
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1$ = 1.528 at node $minRF_2$ = 27 $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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Date: 6 / 17 / 2009
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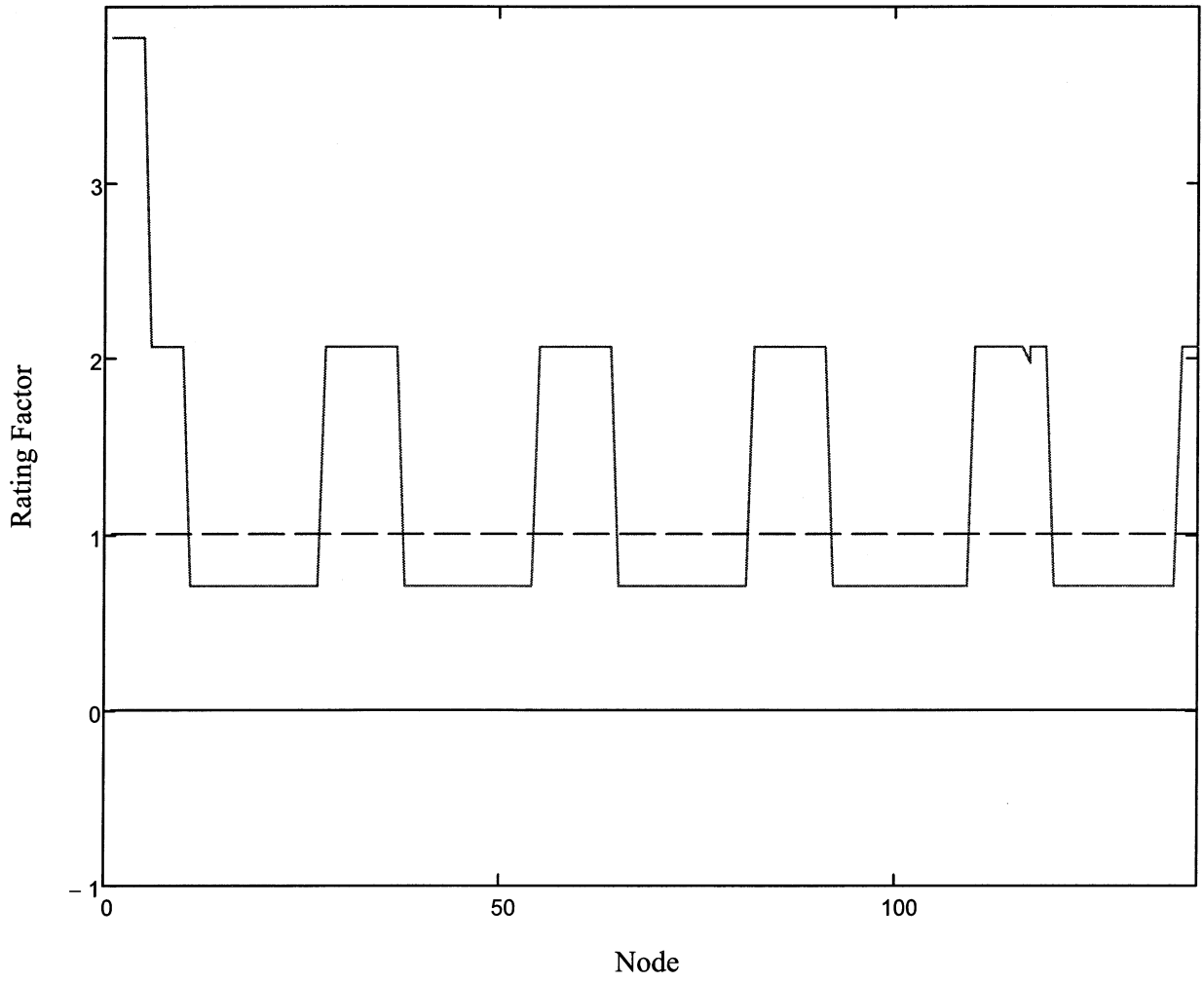
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.97$ at node $minRF_2 = 117$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 5 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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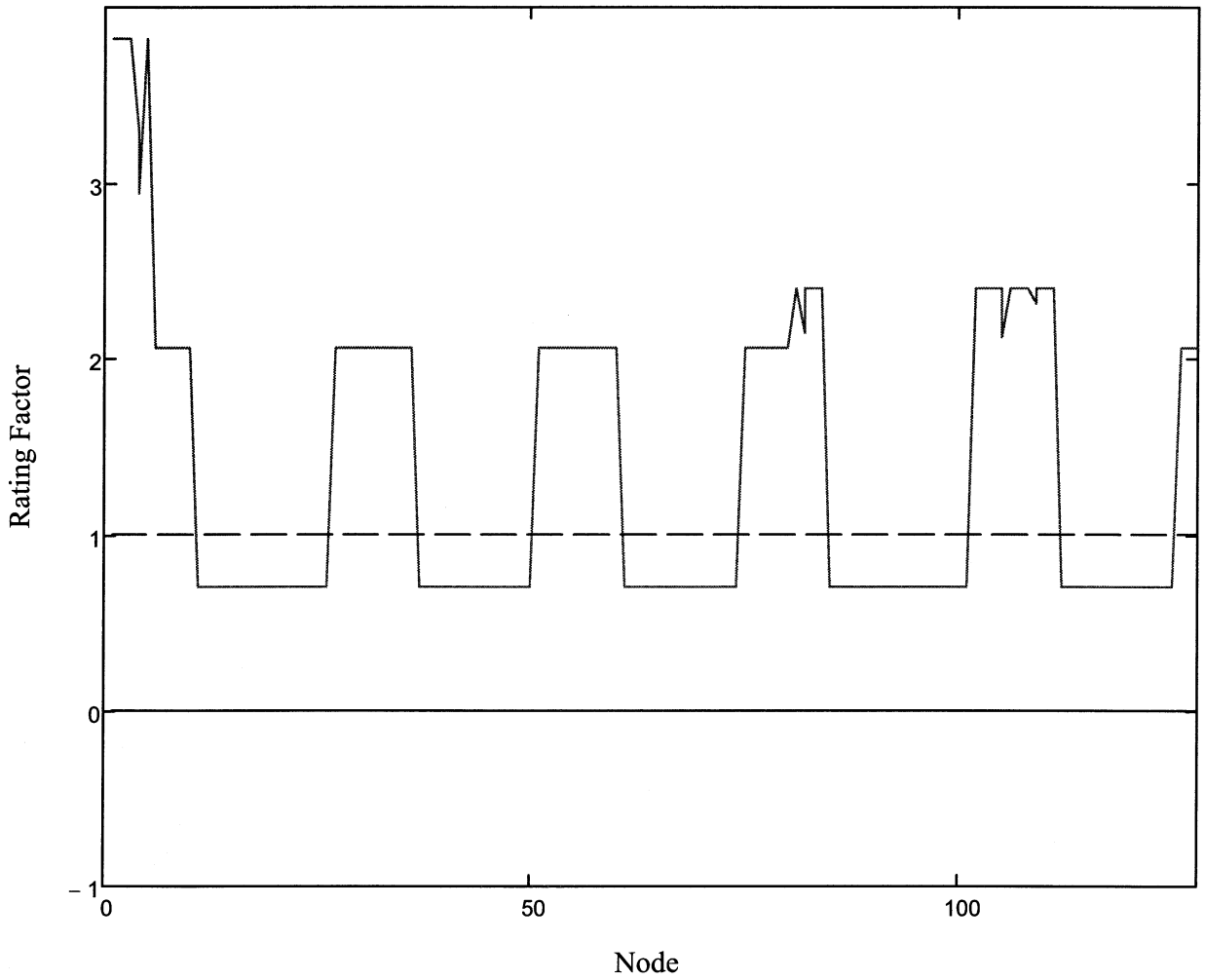
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.064$ at node $minRF_2 = 8$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 6 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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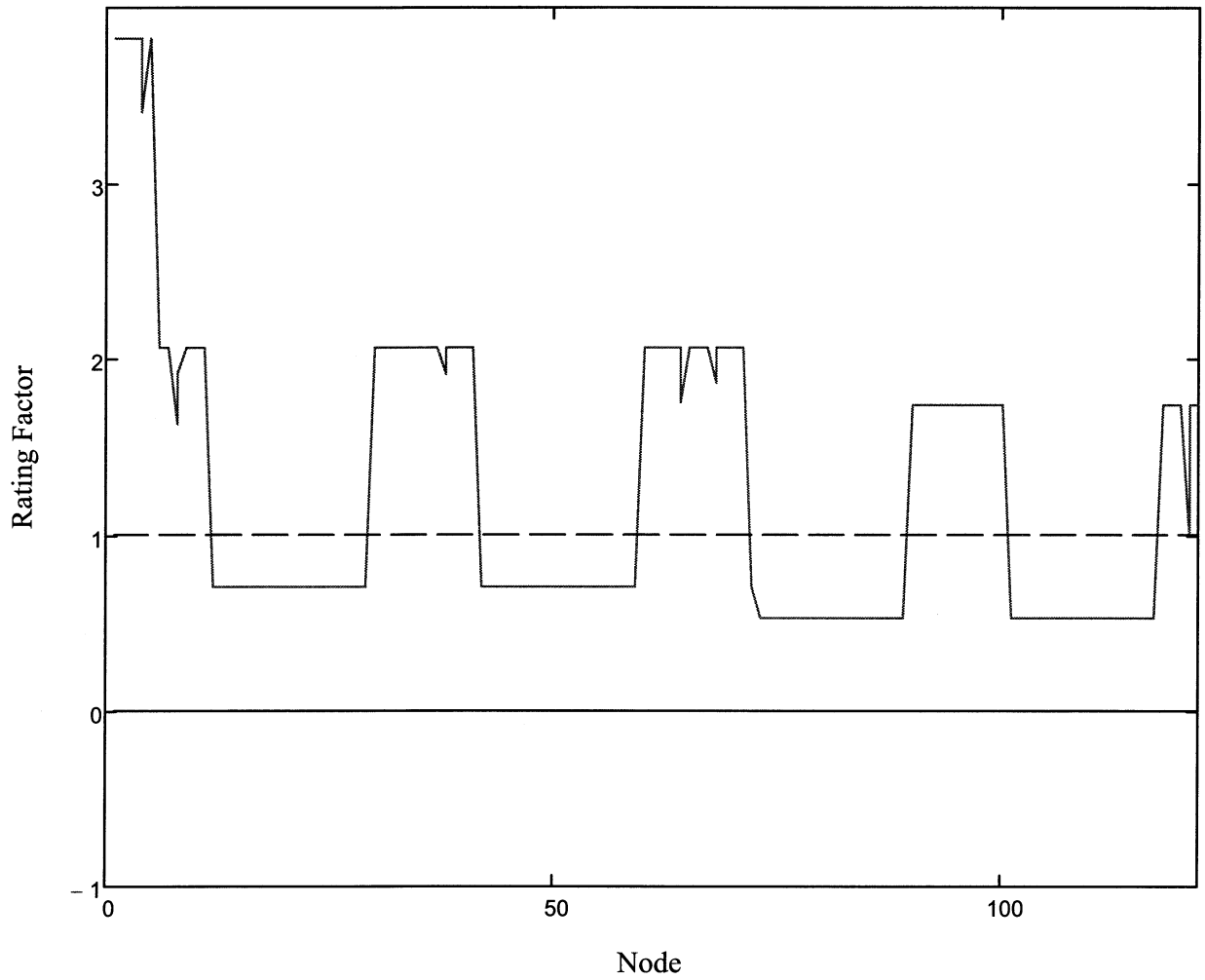
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.993$ at node $minRF_2 = 121$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline --Seg 6 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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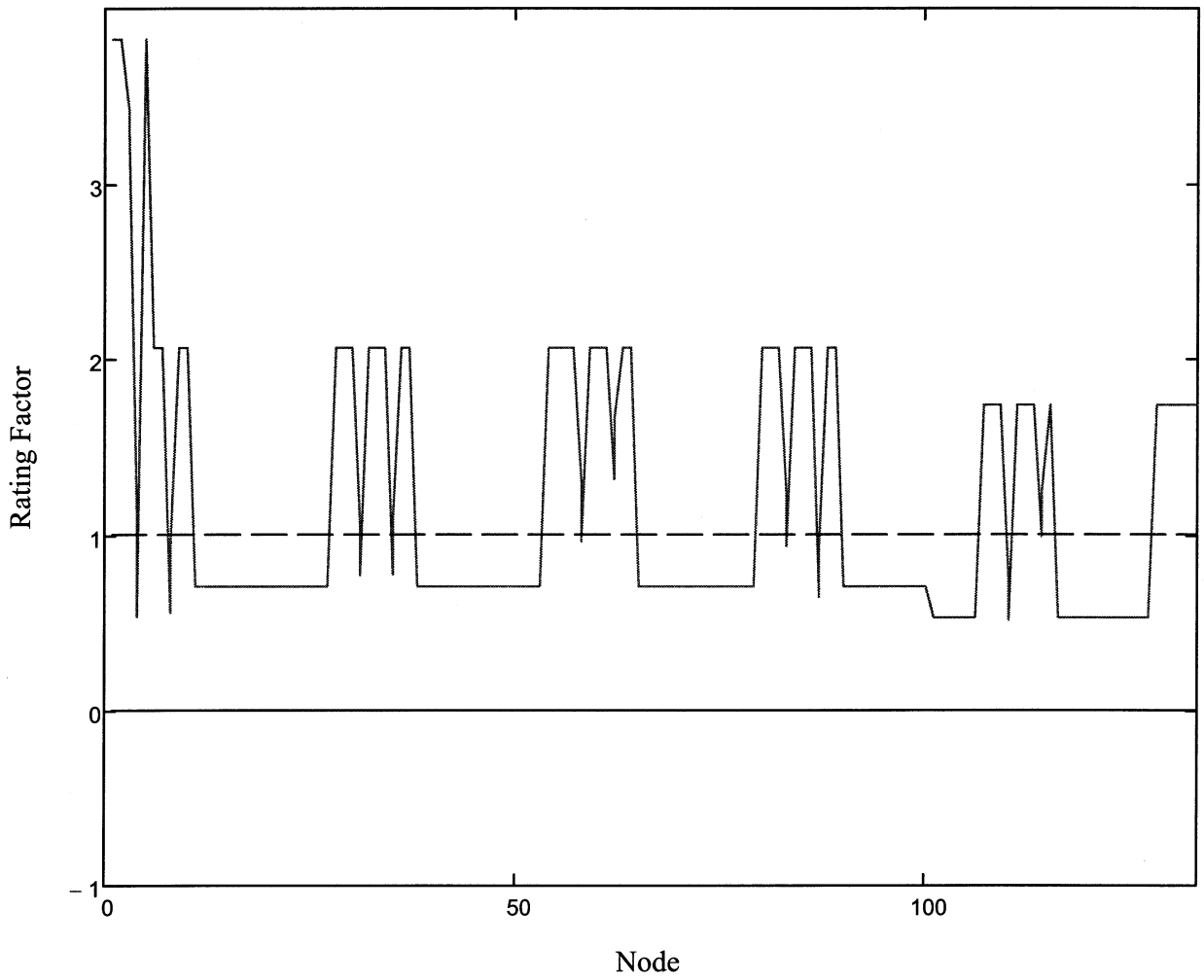
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.514$ at node $minRF_2 = 110$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline--Ramp A
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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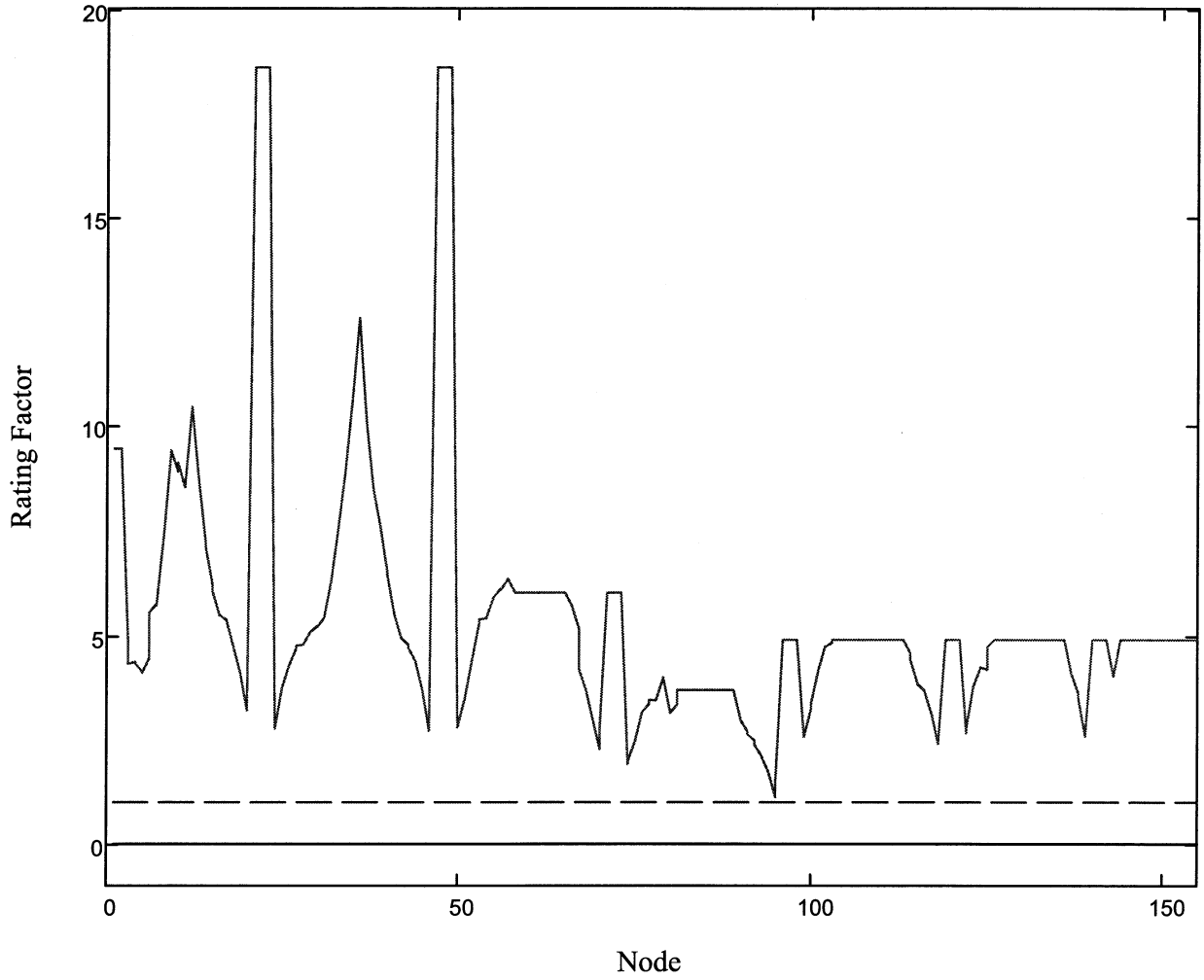
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.121$ at node $minRF_2 = 95$ $minRF_4 =$ "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3 =$ [redacted]

URS

Project: Cline--Ramp A Seg 2
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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Date: 6 / 17 / 2009
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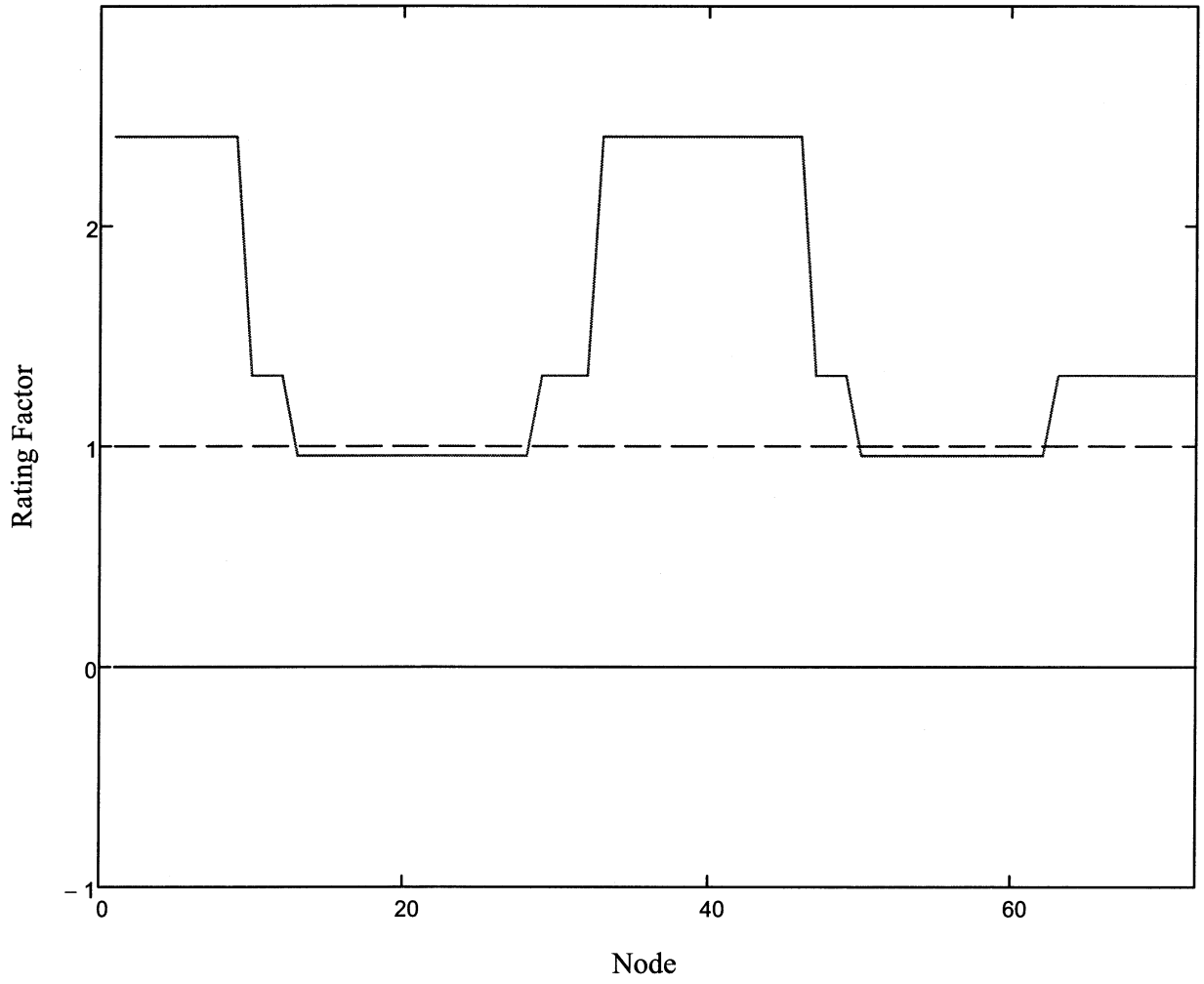
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.931$ at node $minRF_2 = 3$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp A Seg 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
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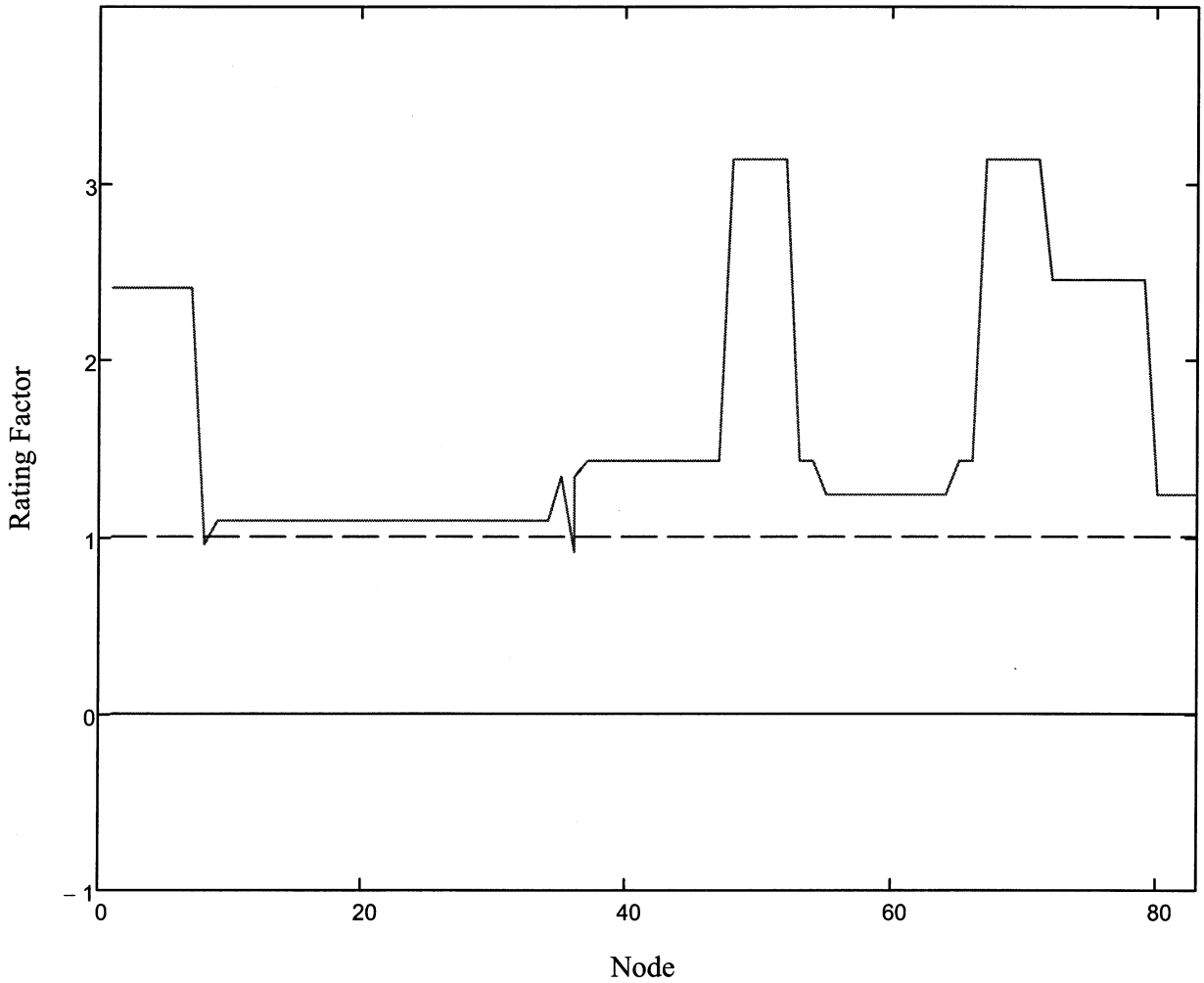
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.914$ at node $minRF_2 = 36$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline--Ramp B
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
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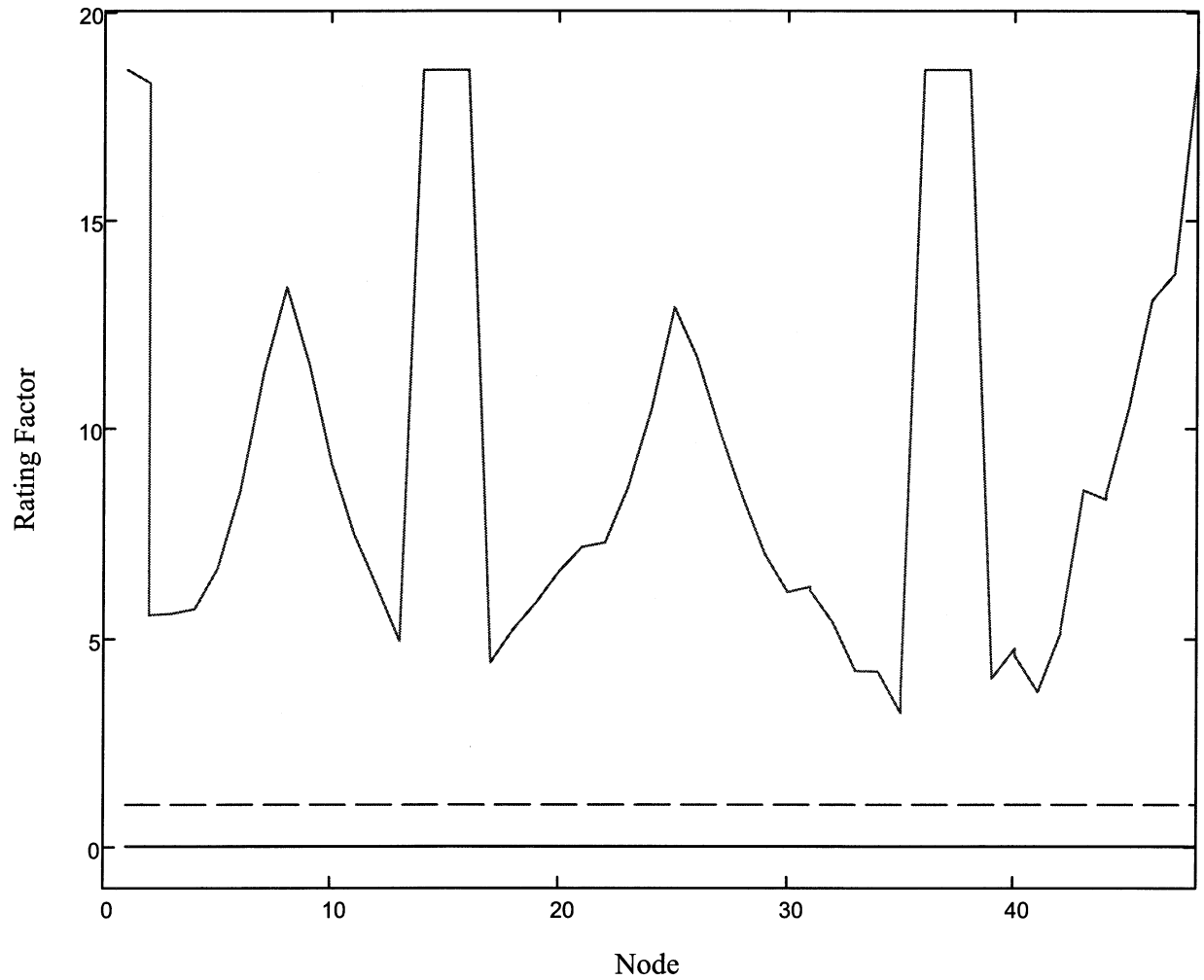
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.193$ at node $minRF_2 = 35$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp B Seg 6
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
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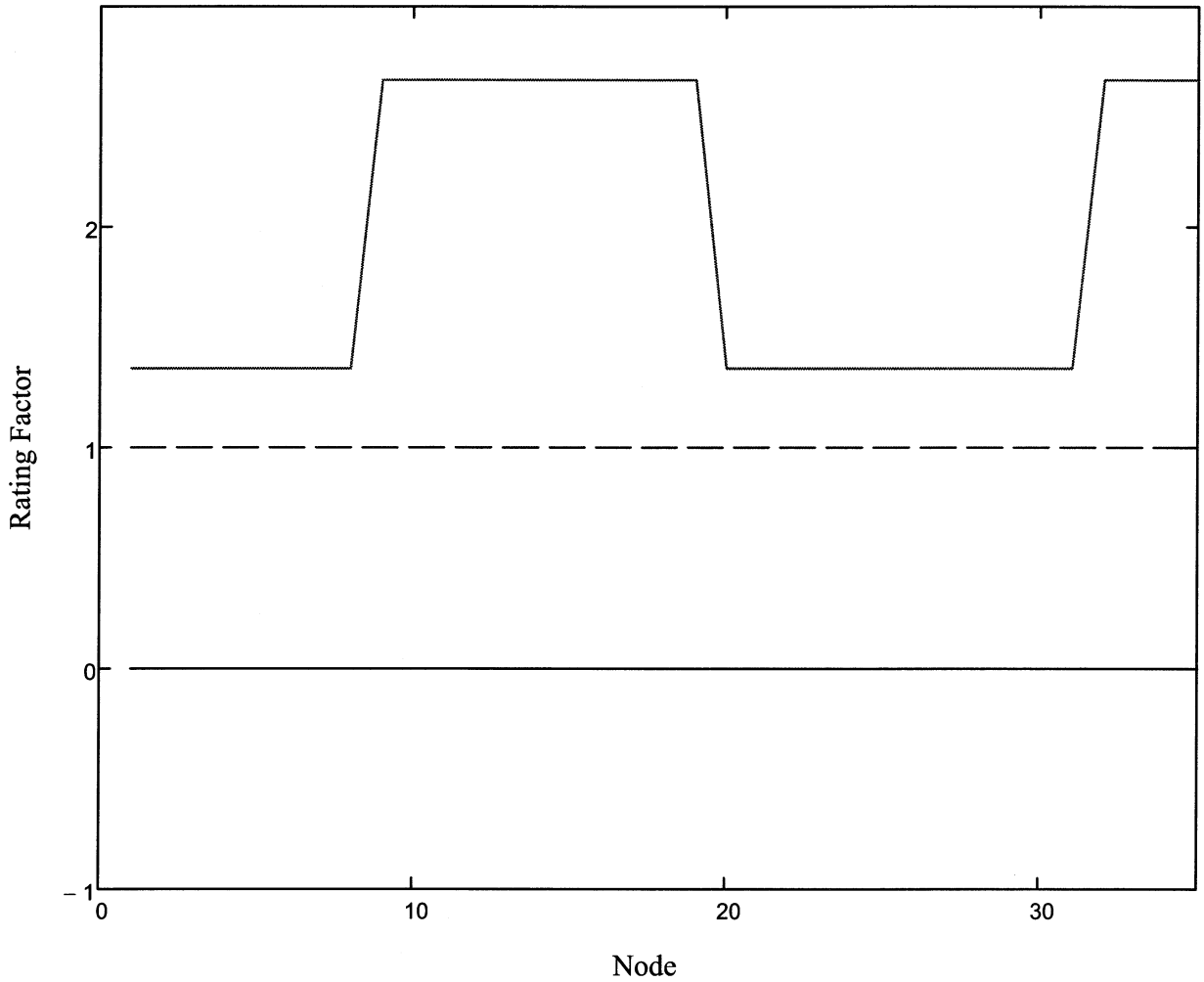
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.319$ at node $minRF_2 = 34$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

URS

Project: Cline--Ramp C Seg 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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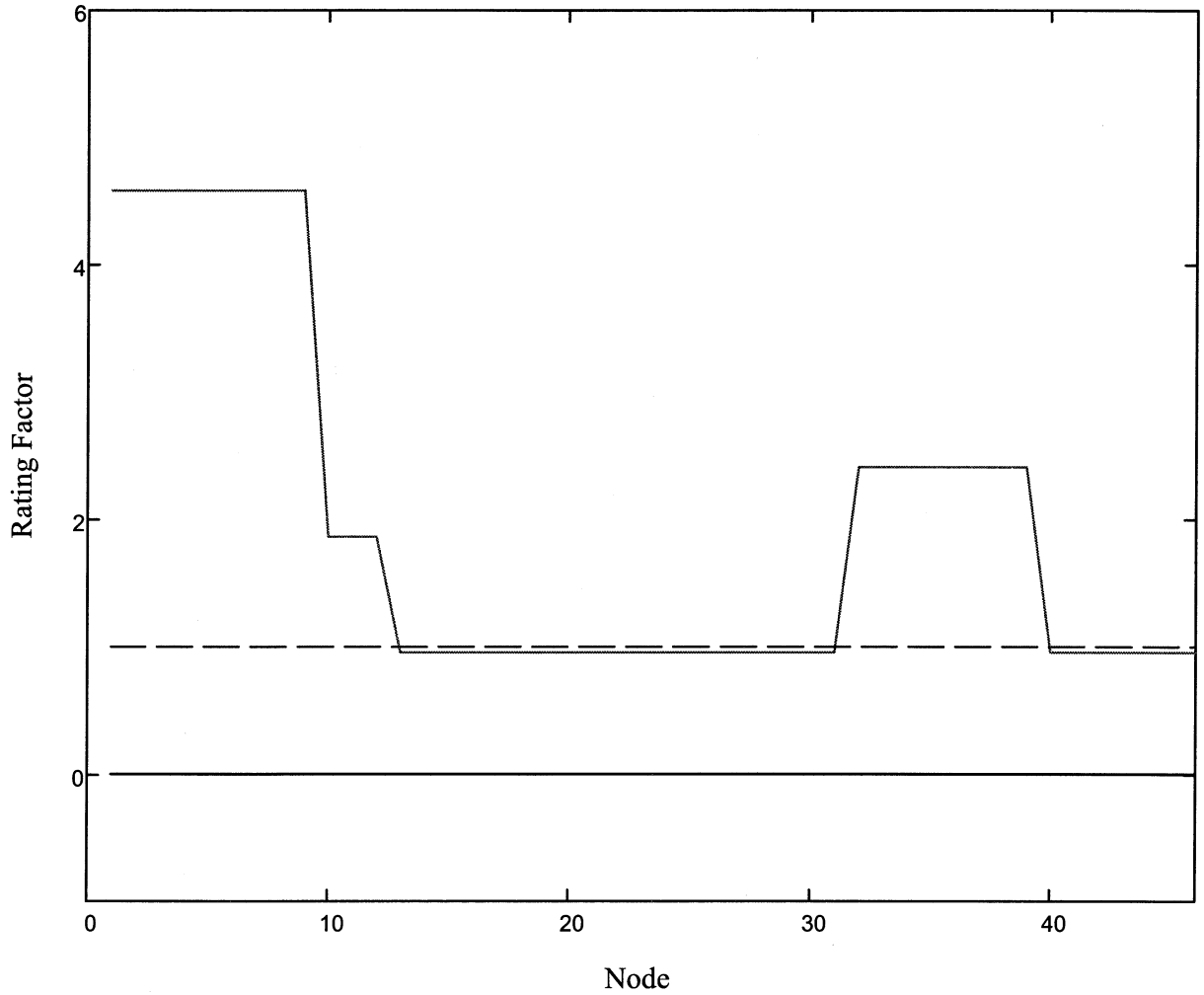
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.005$ at node $minRF_2 = 42$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp C Seg 4
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

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Design: TSP
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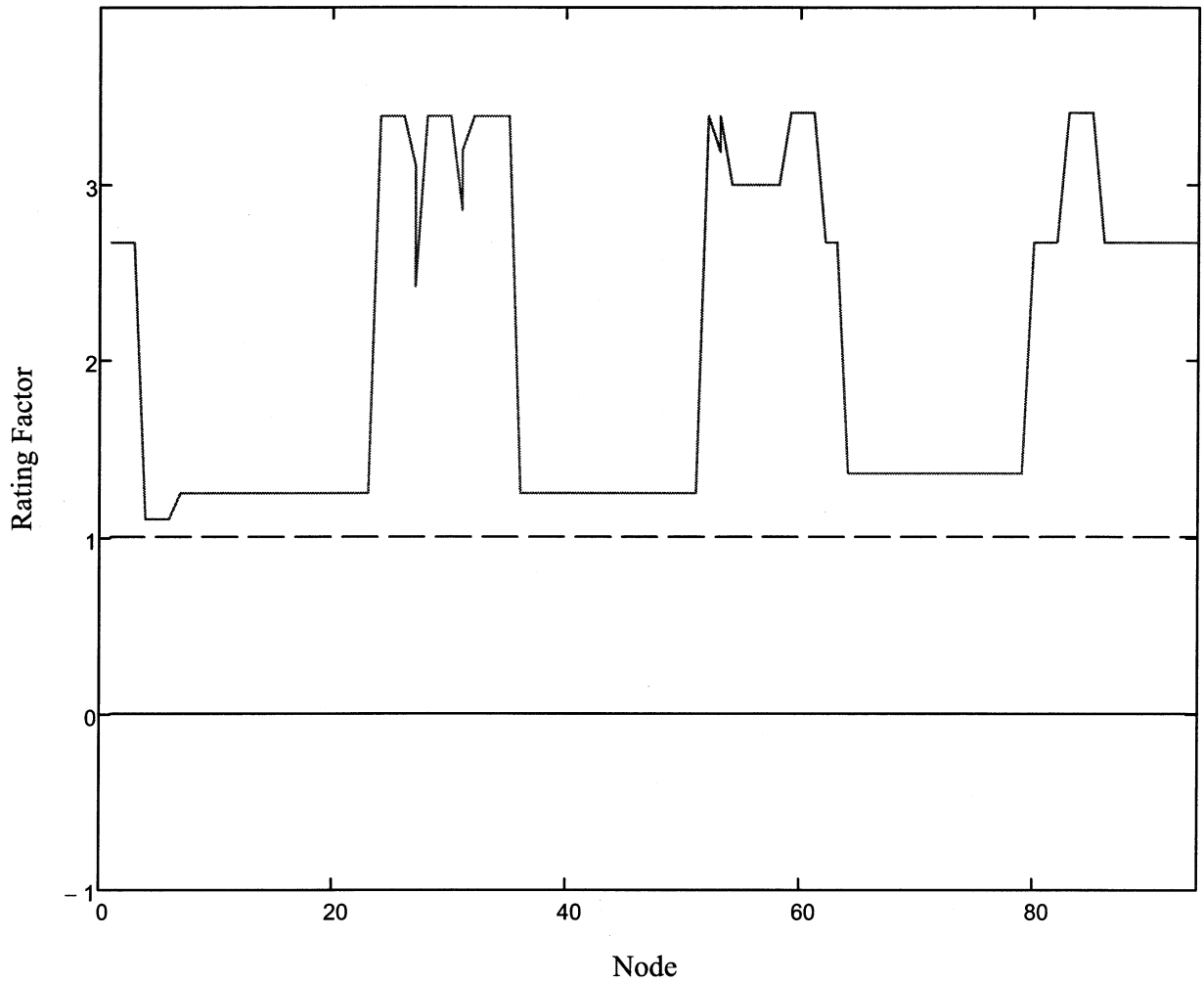
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.417$ at node $minRF_2 = 27$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp C Units 1 & 6-8
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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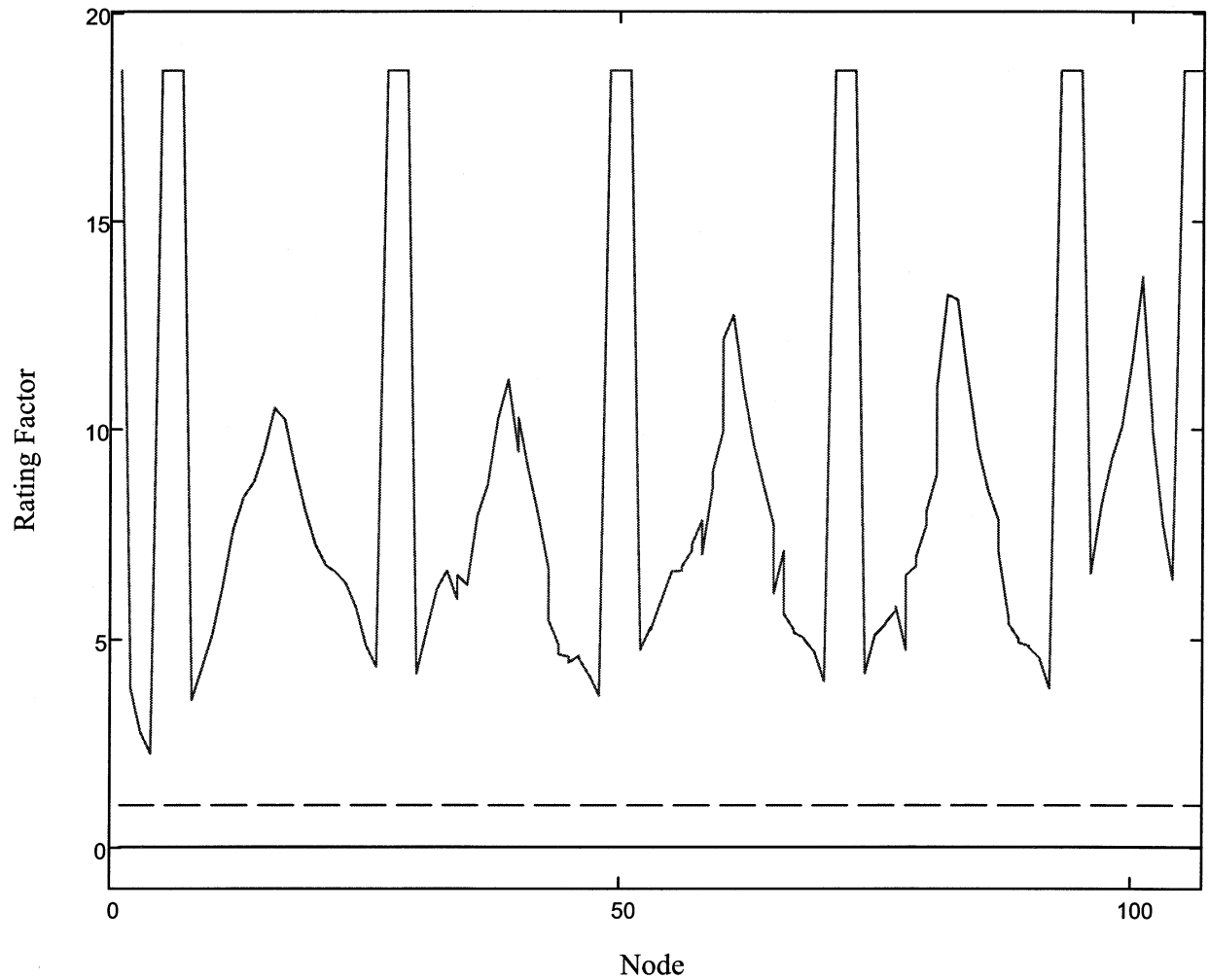
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.242$ at node $minRF_2 = 4$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp C Units 2-5
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

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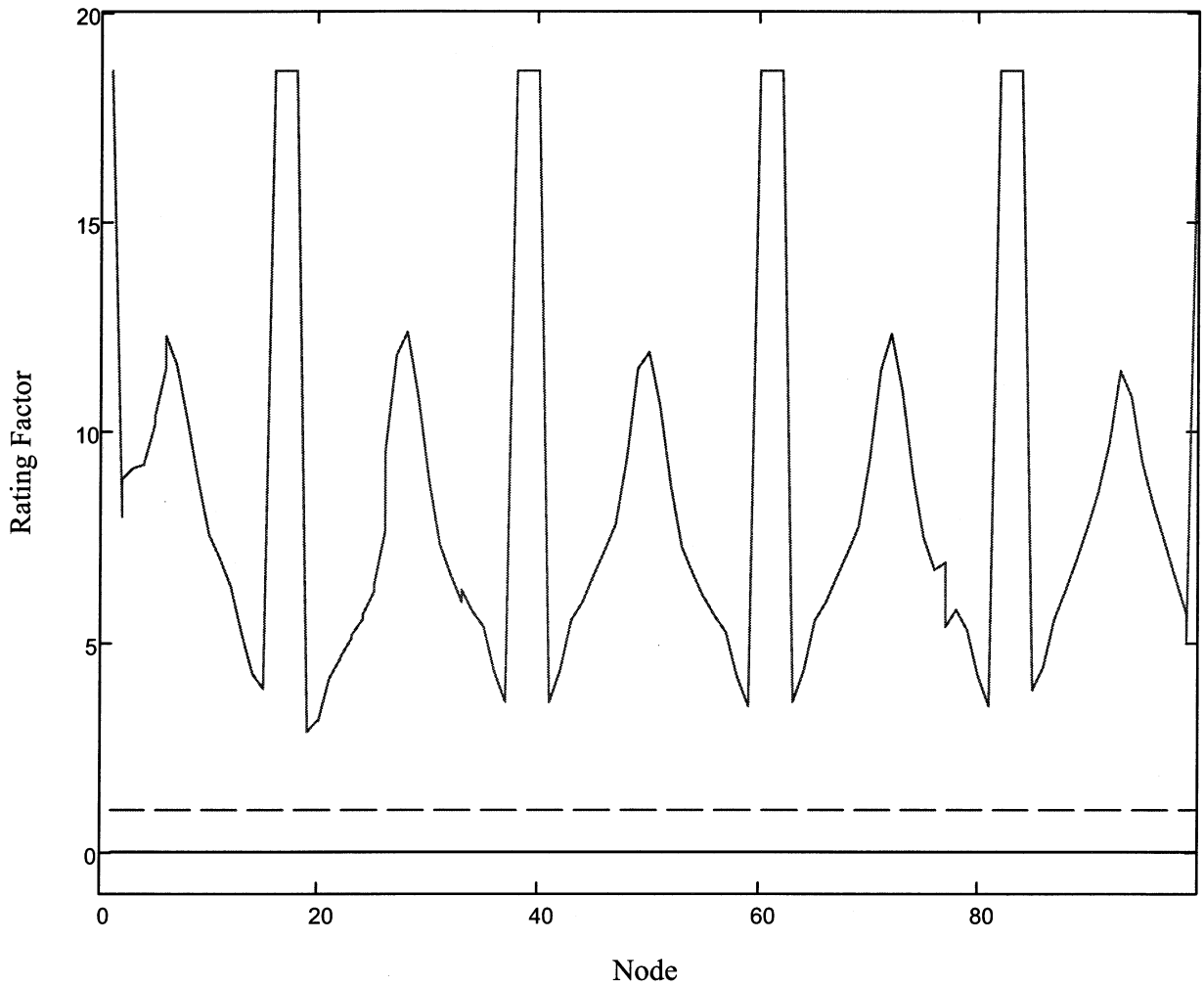
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.86$ at node $minRF_2 = 19$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

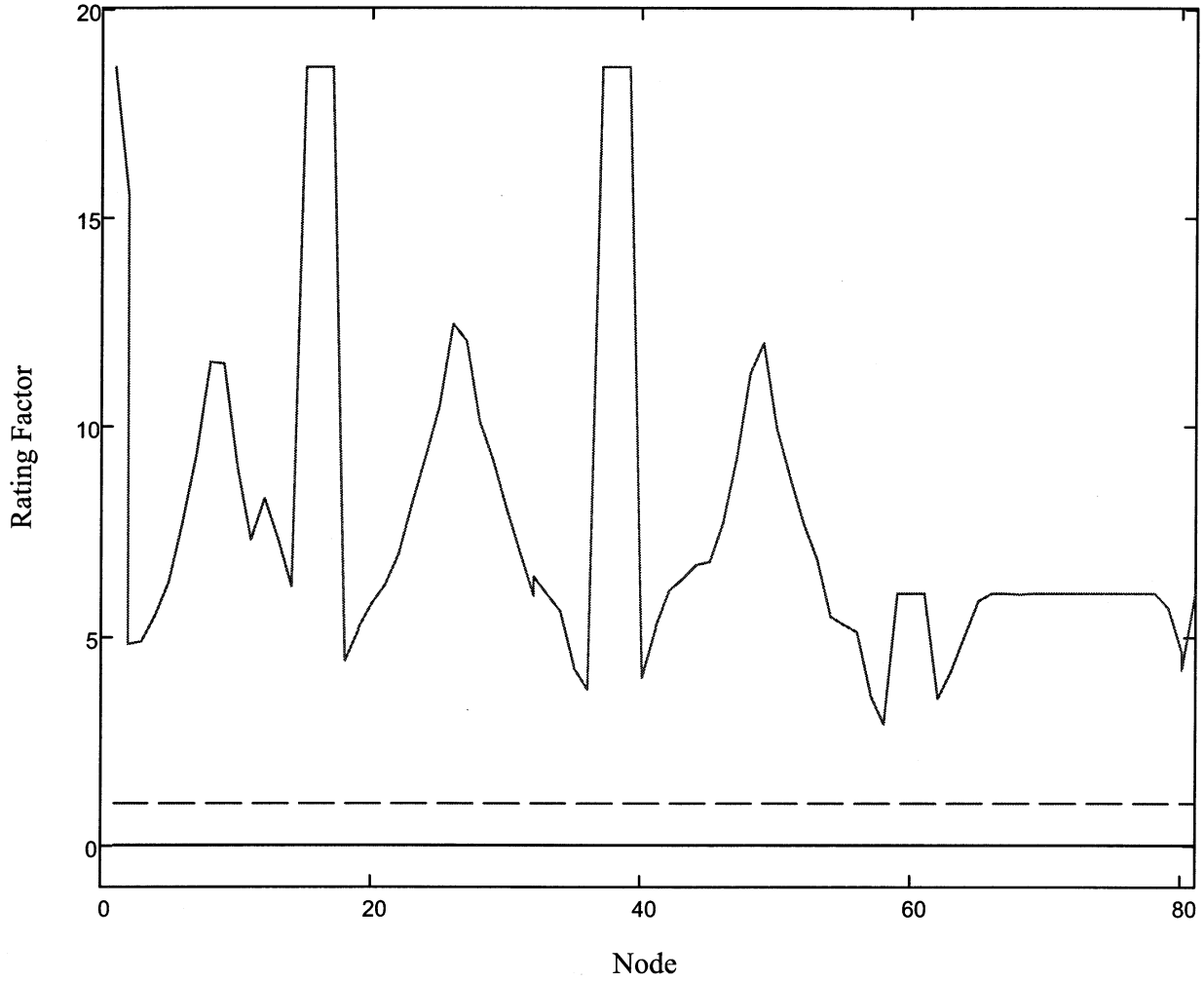
URS

Project: Cline--Ramp D
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.901$ at node $minRF_2 = 58$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

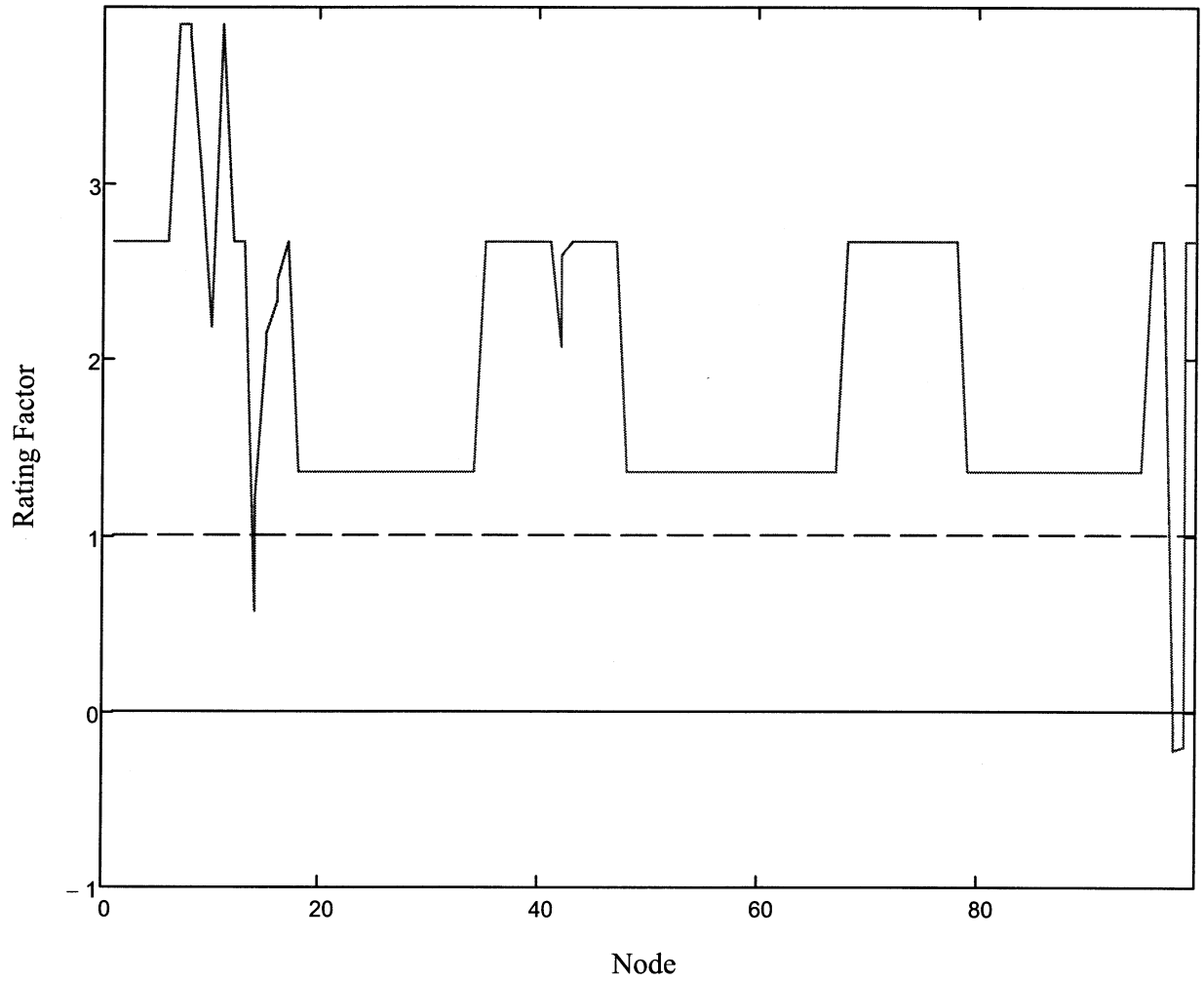
**URS**

Project: Cline--Ramp D Seg 6
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is minRF[redacted]

Striped

8.5/66

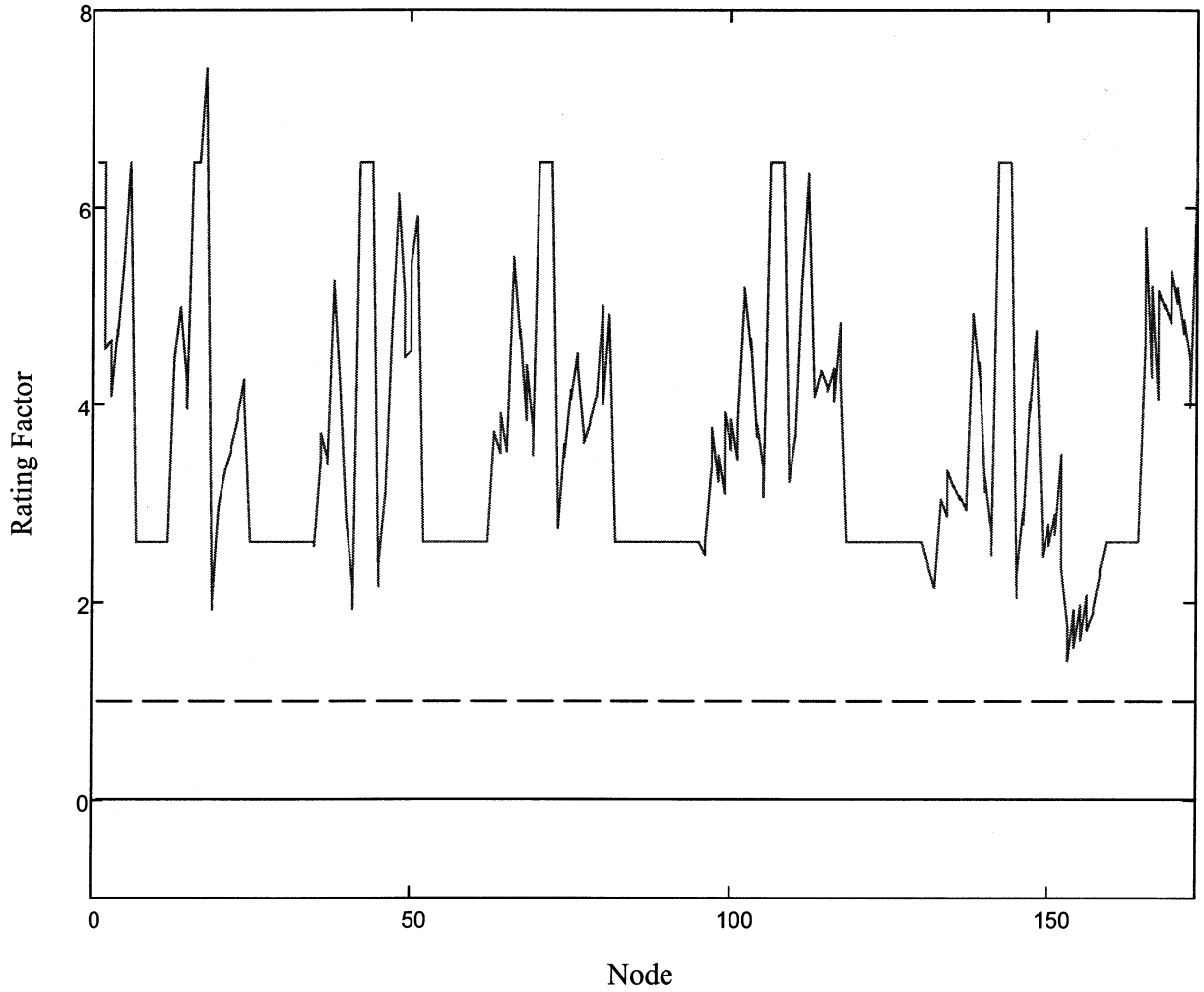
**URS**

Project: Cline --Seg 1 Gdr 1
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.4$ at node $minRF_2 = 153$ $minRF_4$ = "Ahead"

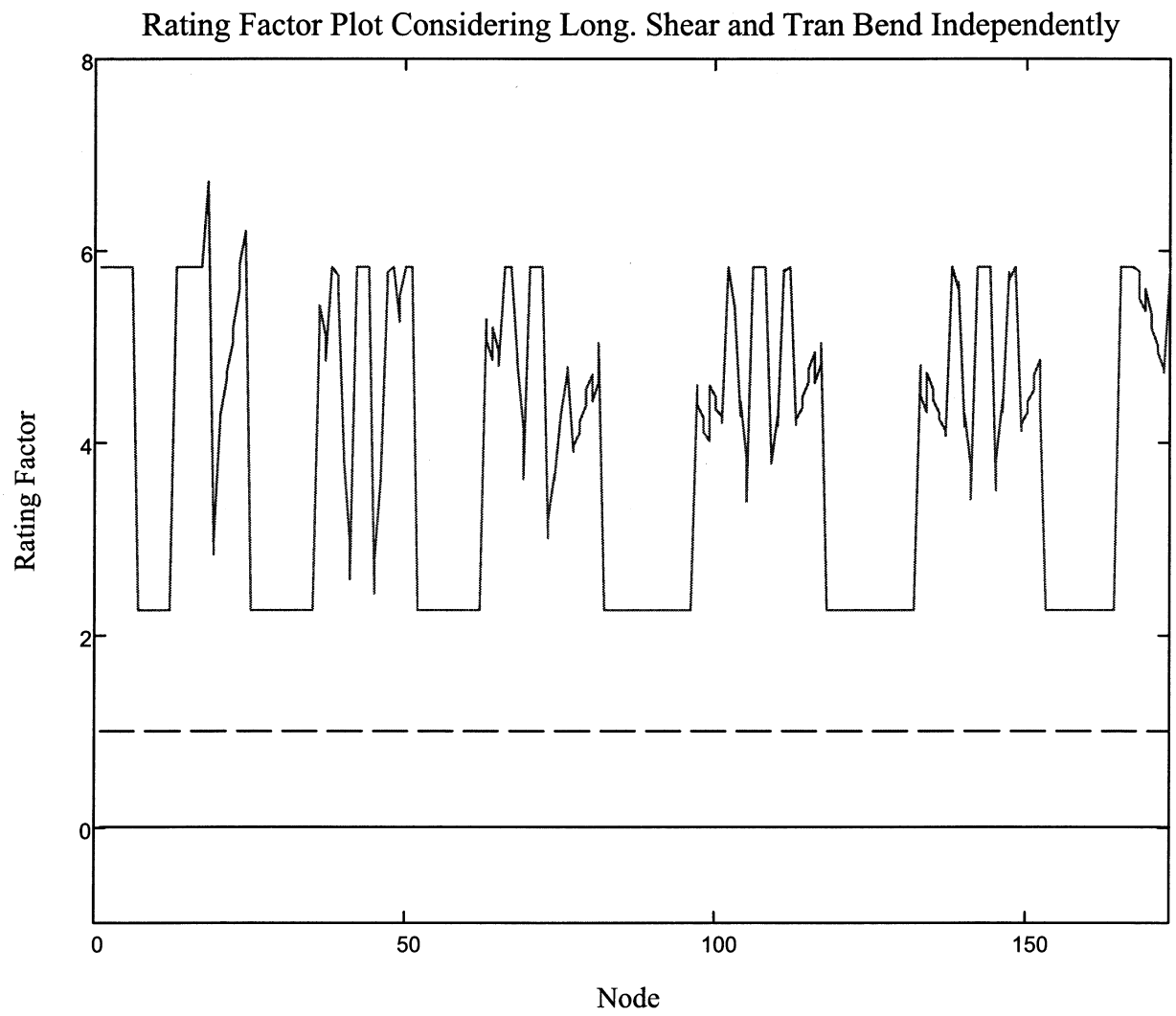
Minimum Rating Factor for Transverse Bending is minR[redacted]

URS

Project: Cline --Seg 1 Gdr 2
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.429$ at node $minRF_2 = 45$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

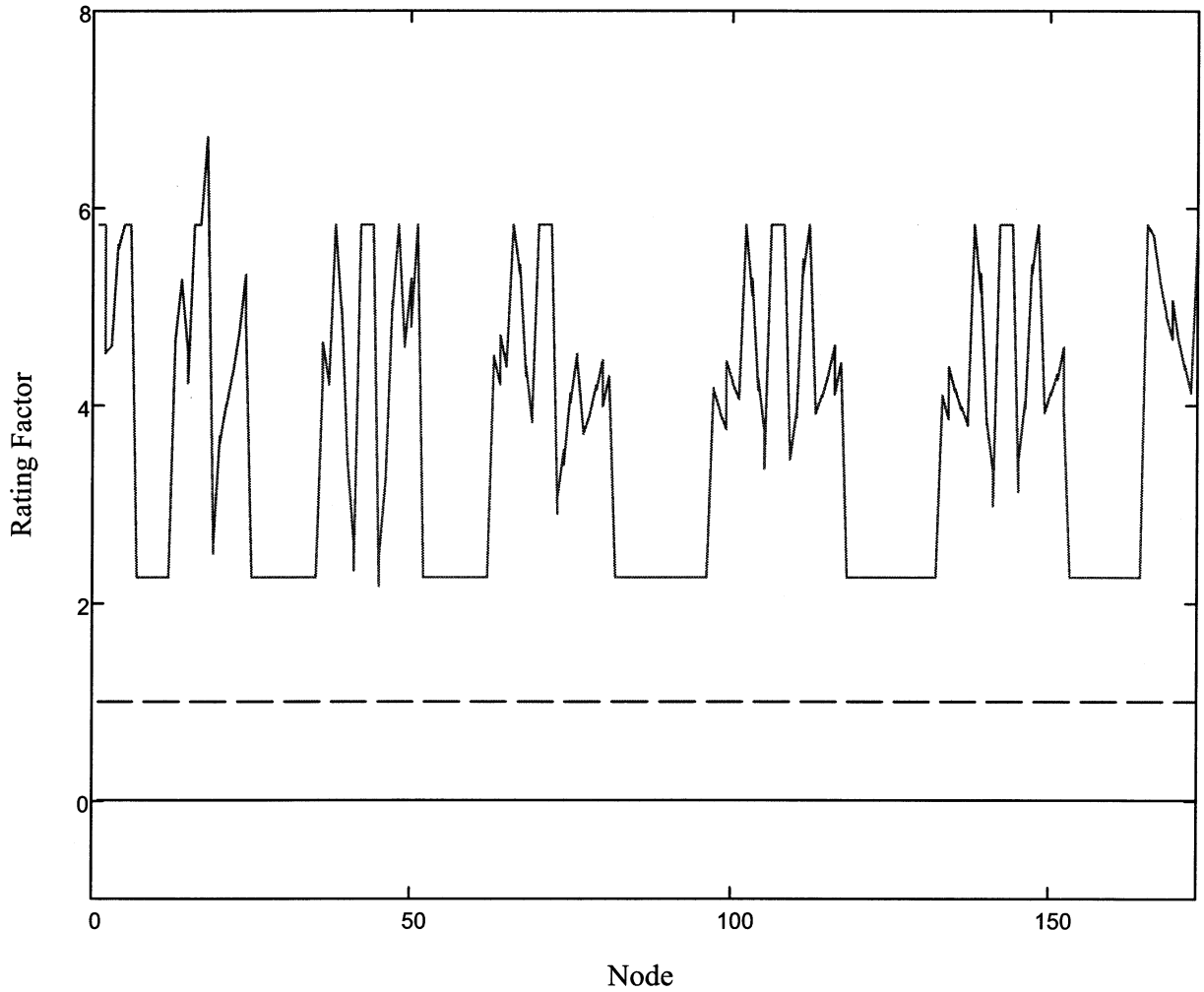
URS

Project: Cline --Seg 1 Gdr 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.167$ at node $minRF_2 = 45$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

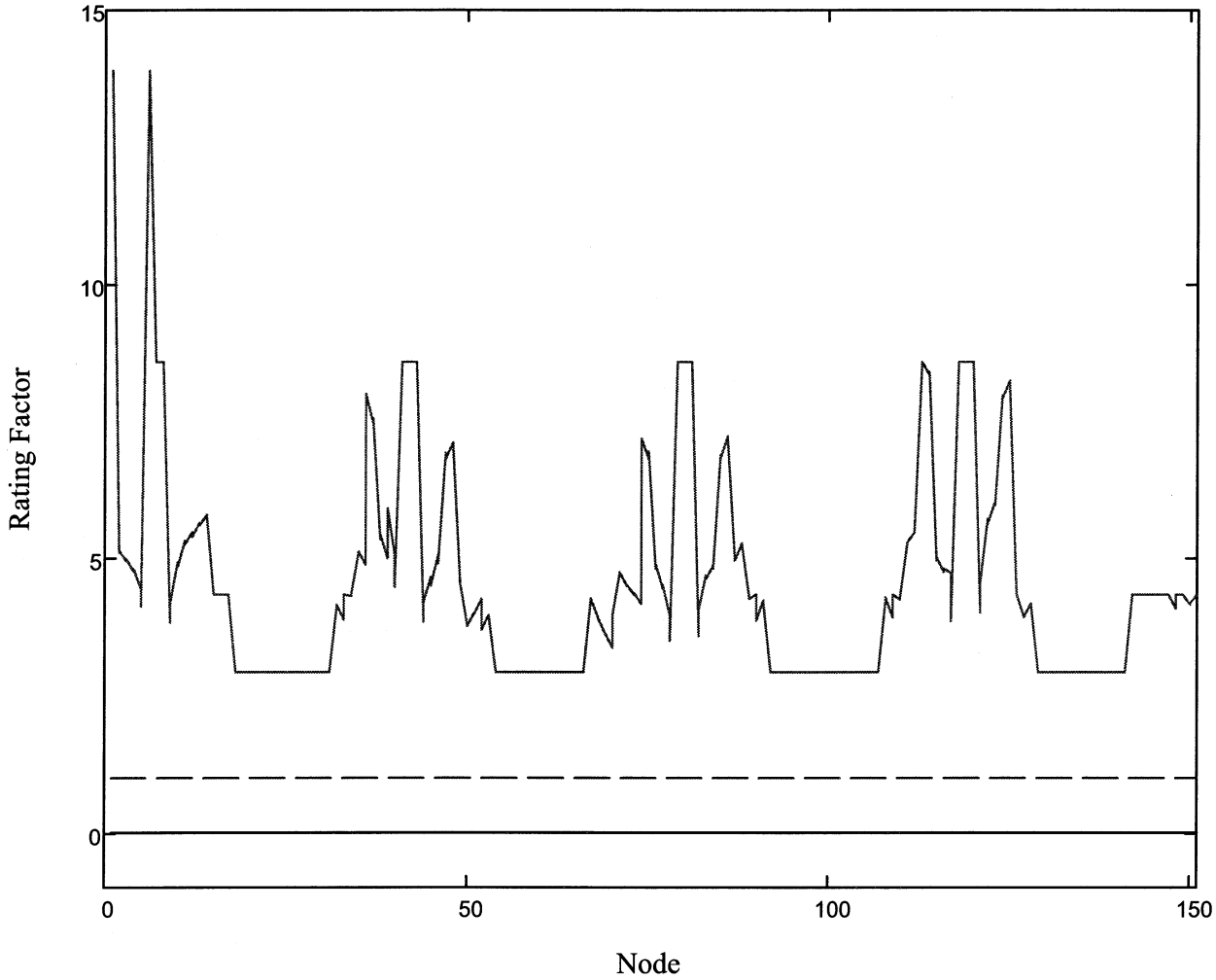
URS

Project: Cline --Seg 2 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.339$ at node $minRF_2 = 129$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is minRF[redacted]

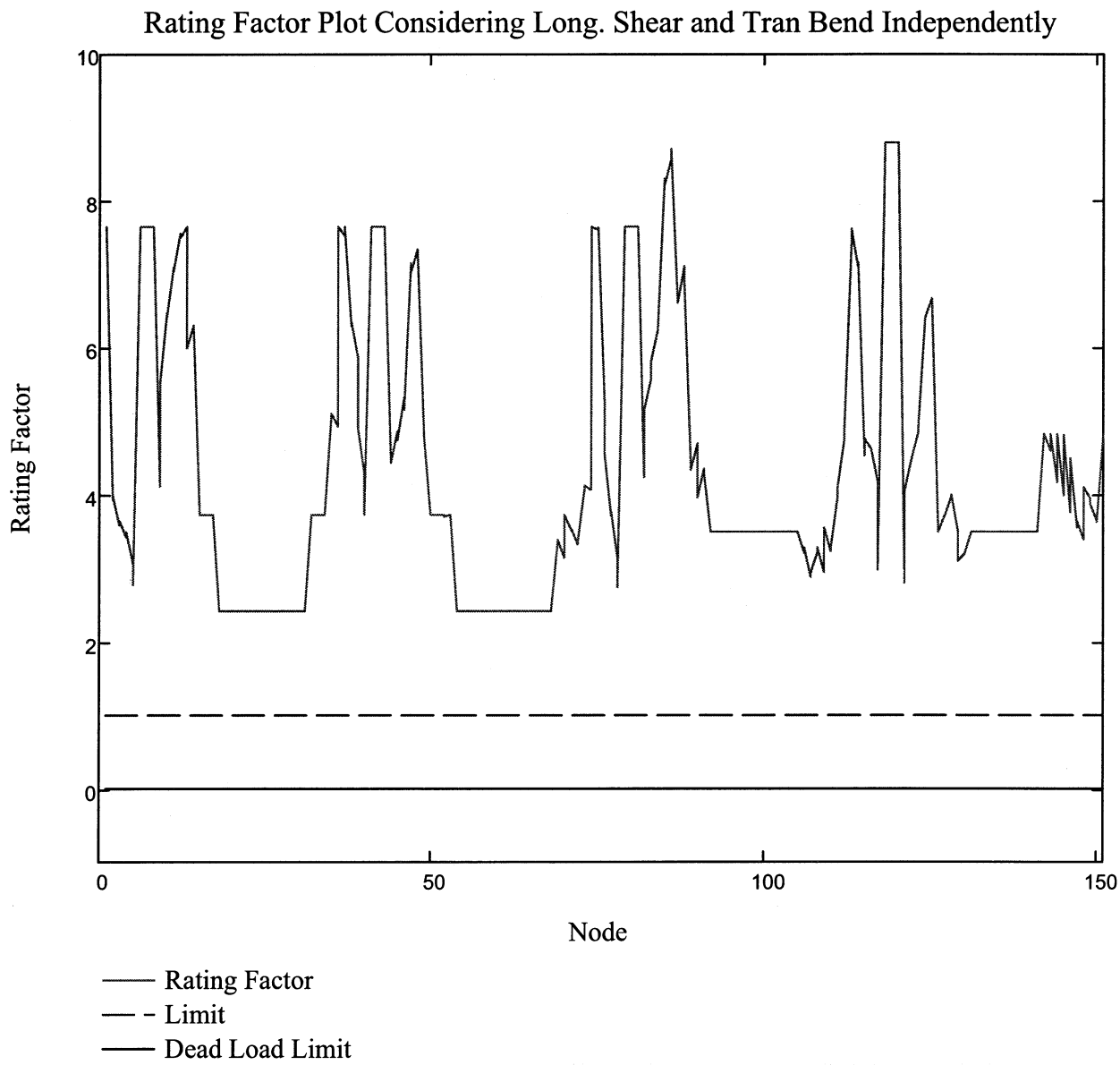
8.5/70

URS

Project: Cline --Seg 2 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.738$ at node $minRF_2 = 78$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is minRF[redacted]

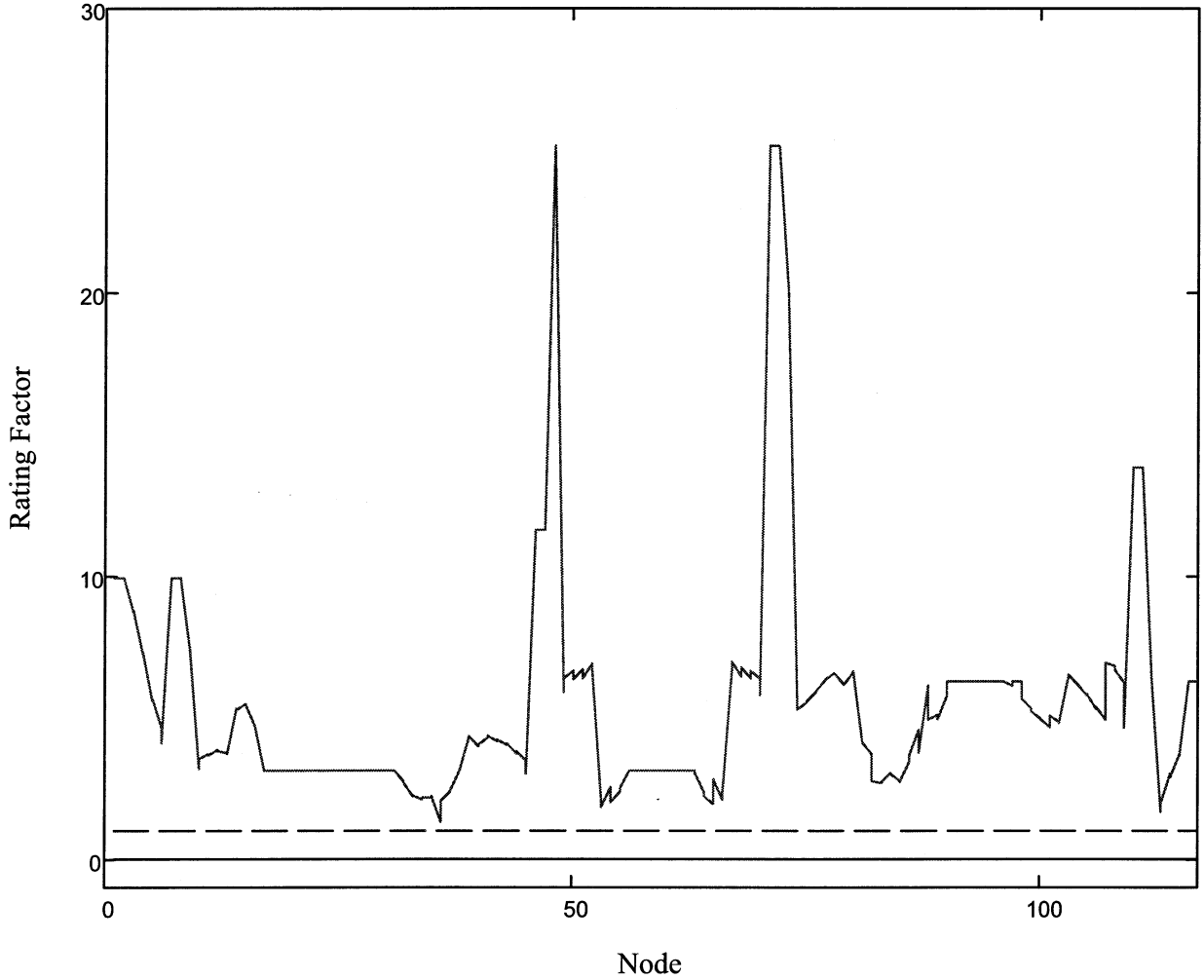
URS

Project: Cline --Seg 3 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently



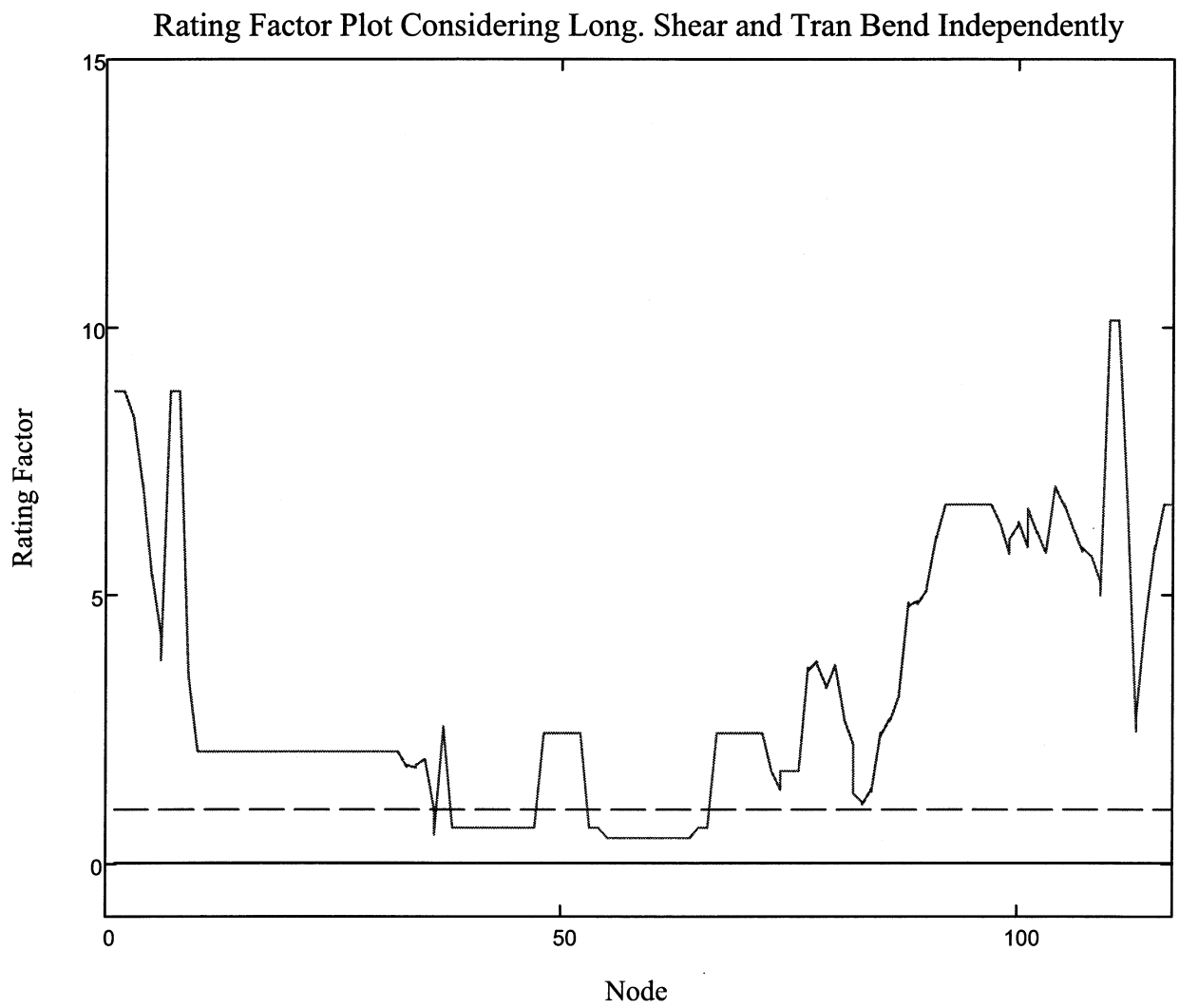

—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.311$ at node $minRF_2 = 36$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is minR[redacted]

8.5/72

| URS | Job No. 25626272.00001 | Page _____ |
|---|---|---|
| Project: Cline --Seg 3 WB | | |
| Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc | Design: TSP | Date: 6 / 17 / 2009 |
| | Check: Ind Chk | Date: / / |




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.532$ at node $minRF_2 = 36$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

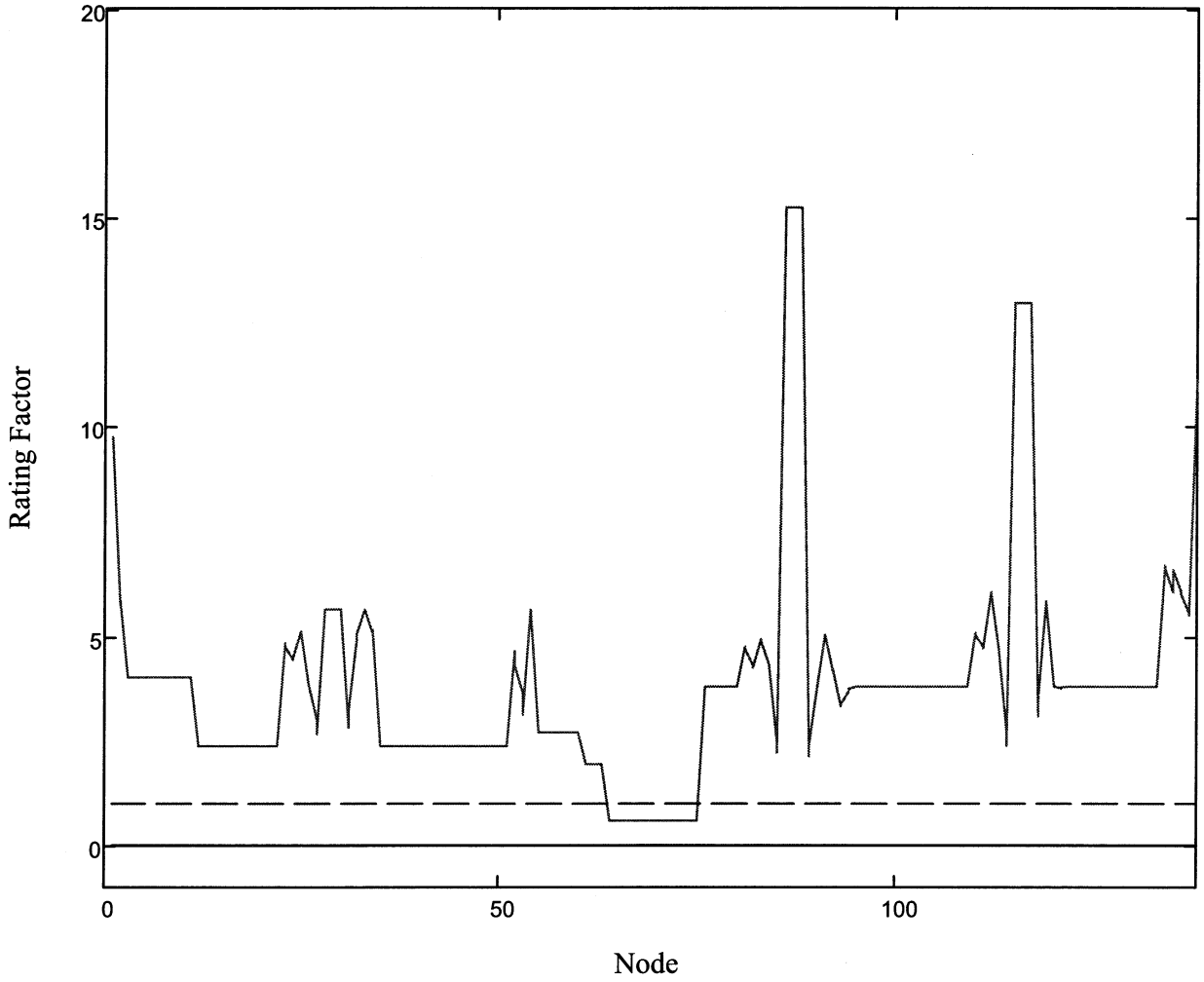
URS

Project: Cline --Seg 4 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.134$ at node $minRF_2 = 89$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is minRF[redacted]

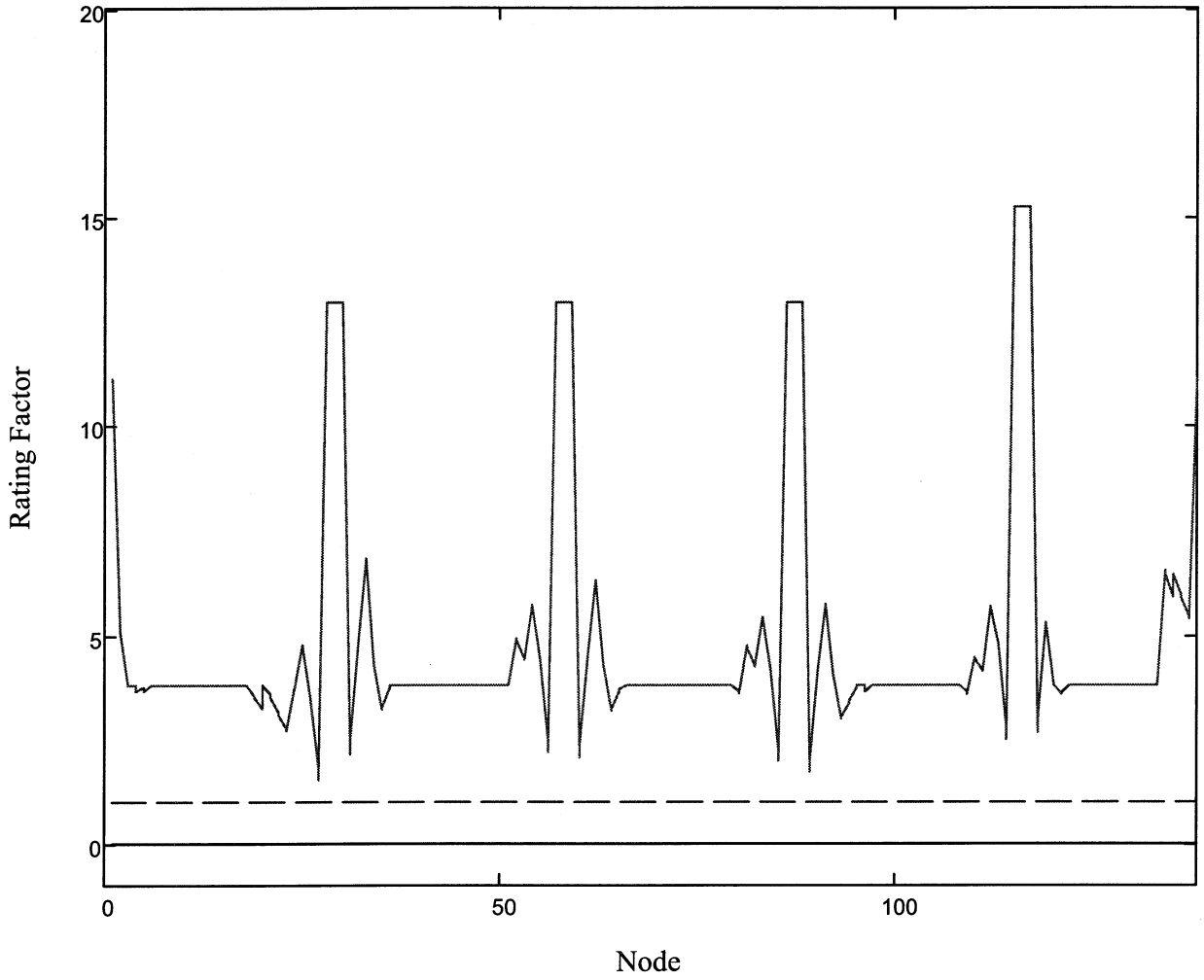
URS

Project: Cline --Seg 4 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.528$ at node $minRF_2 = 27$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is minR[redacted]

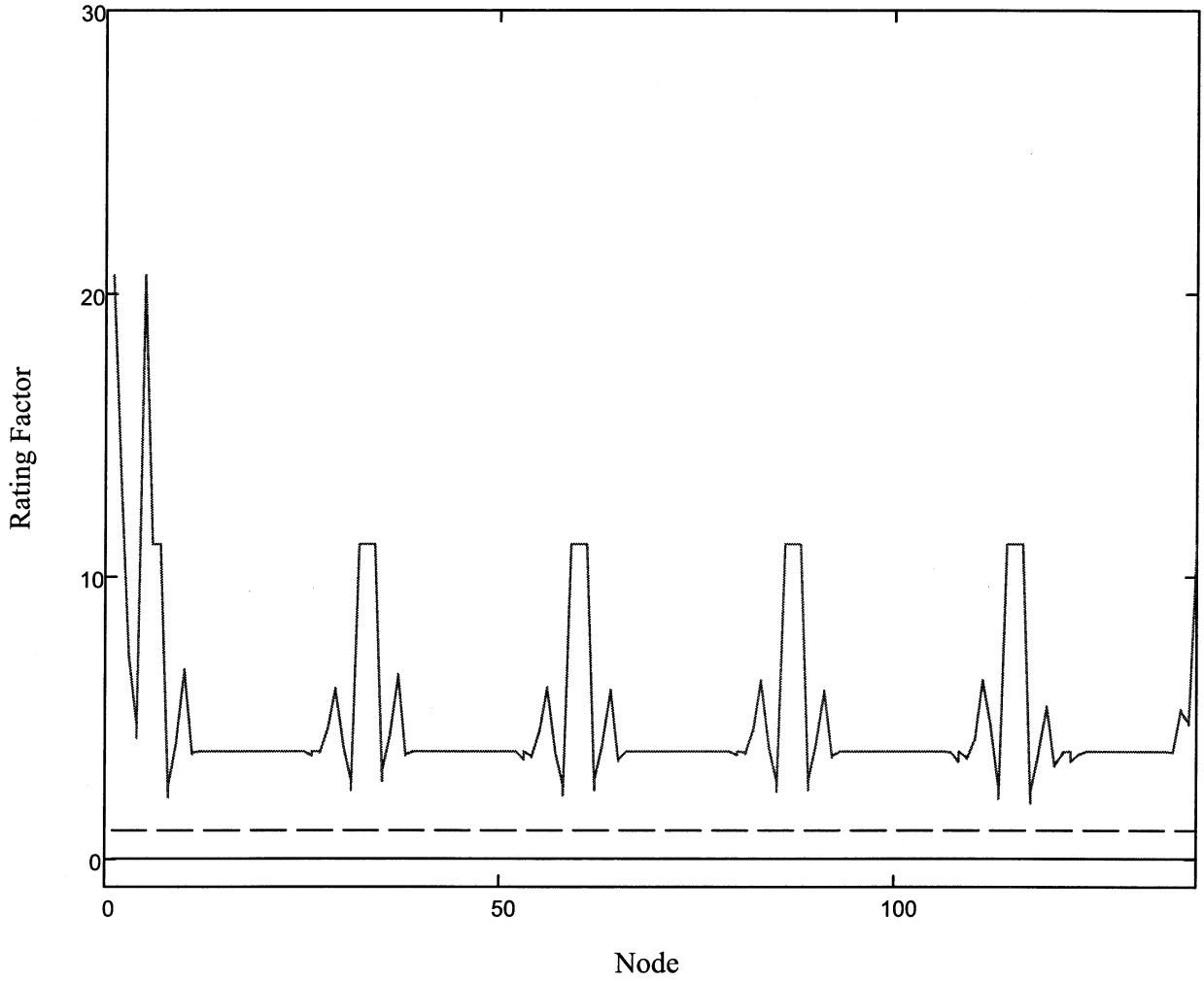
**URS**

Project: Cline --Seg 5 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.97$ at node $minRF_2 = 117$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is minR[redacted]

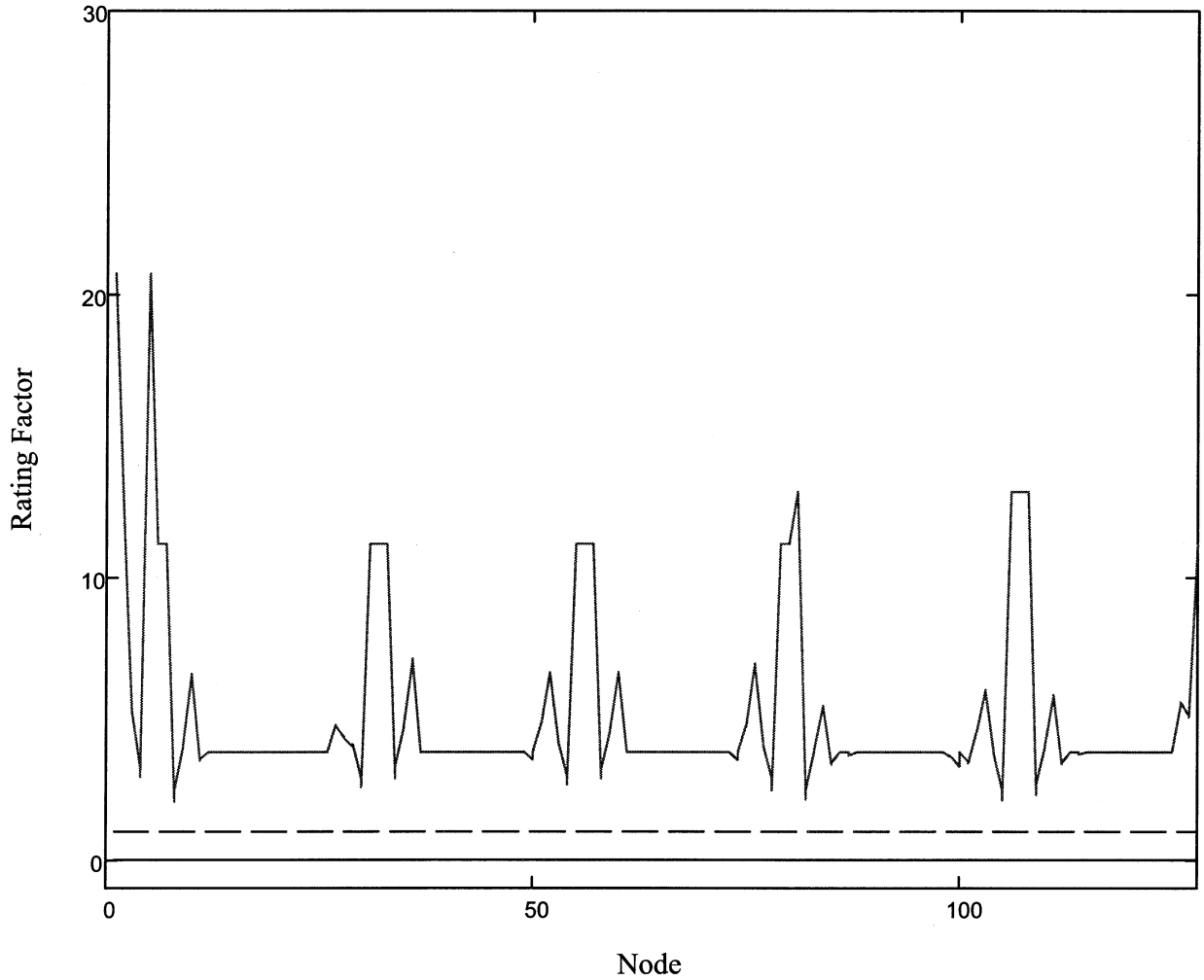
URS

Project: Cline --Seg 5 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.064$ at node $minRF_2 = 8$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

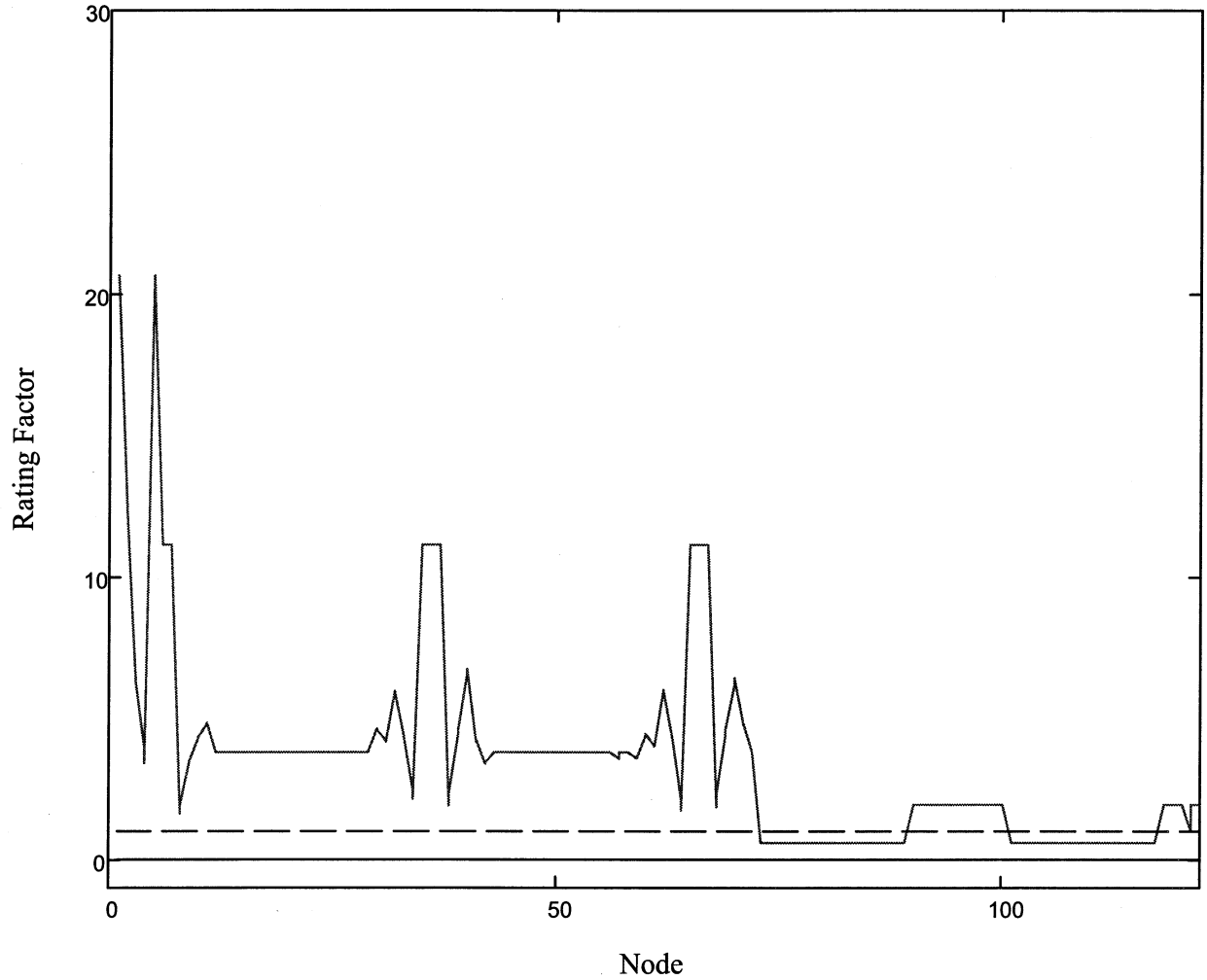
URS

Project: Cline --Seg 6 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.993$ at node $minRF_2 = 121$ $minRF_4$ = "Back"

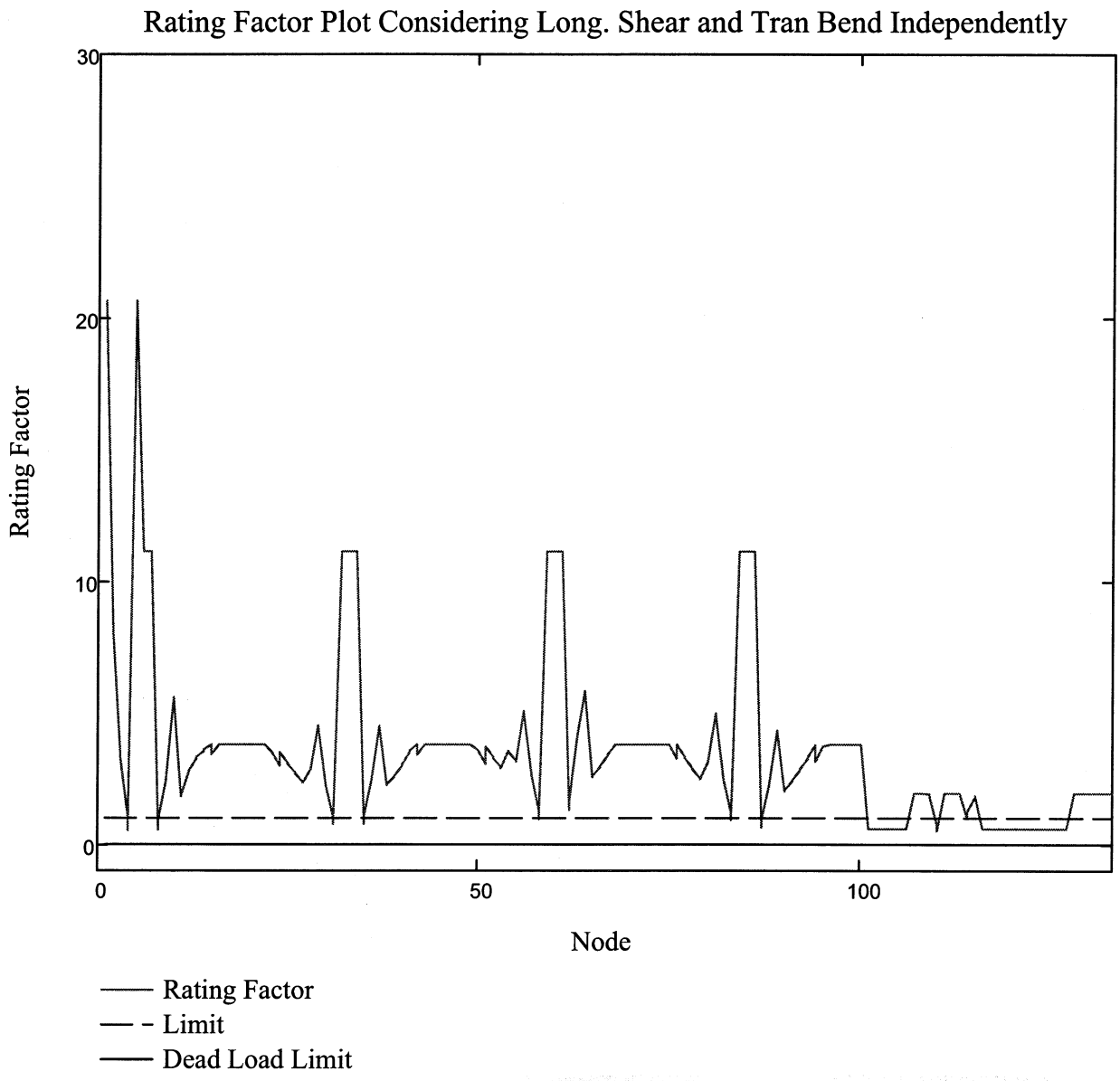
Minimum Rating Factor for Transverse Bending is minR[redacted]

URS

Project: Cline --Seg 6 WB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.514$ at node $minRF_2 = 110$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is minRF[redacted]

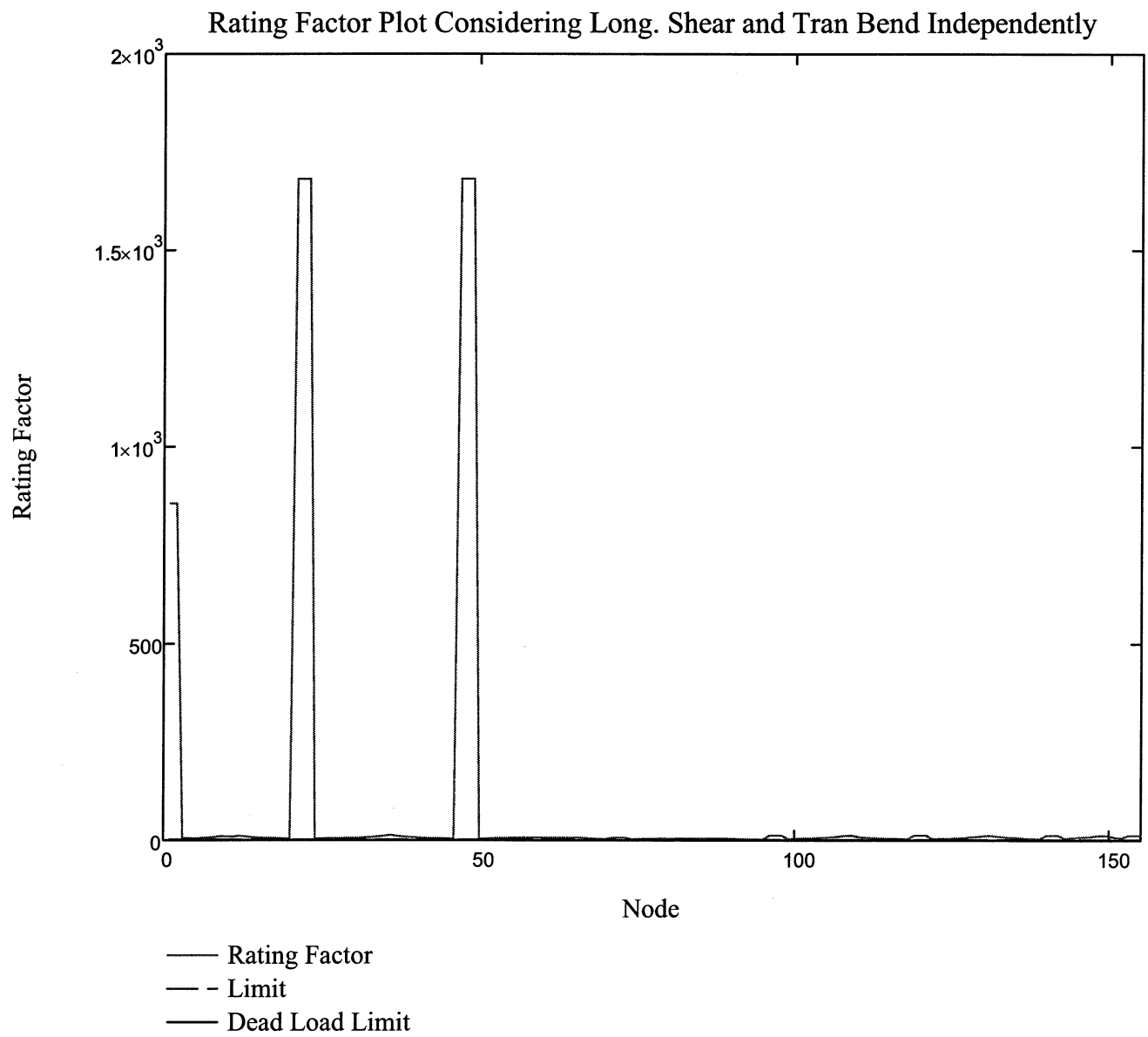
8.5/79

**URS**

Project: Cline--Ramp A
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 1.121$ at node $minRF_2 = 95$ $minRF_4$ = "Back"

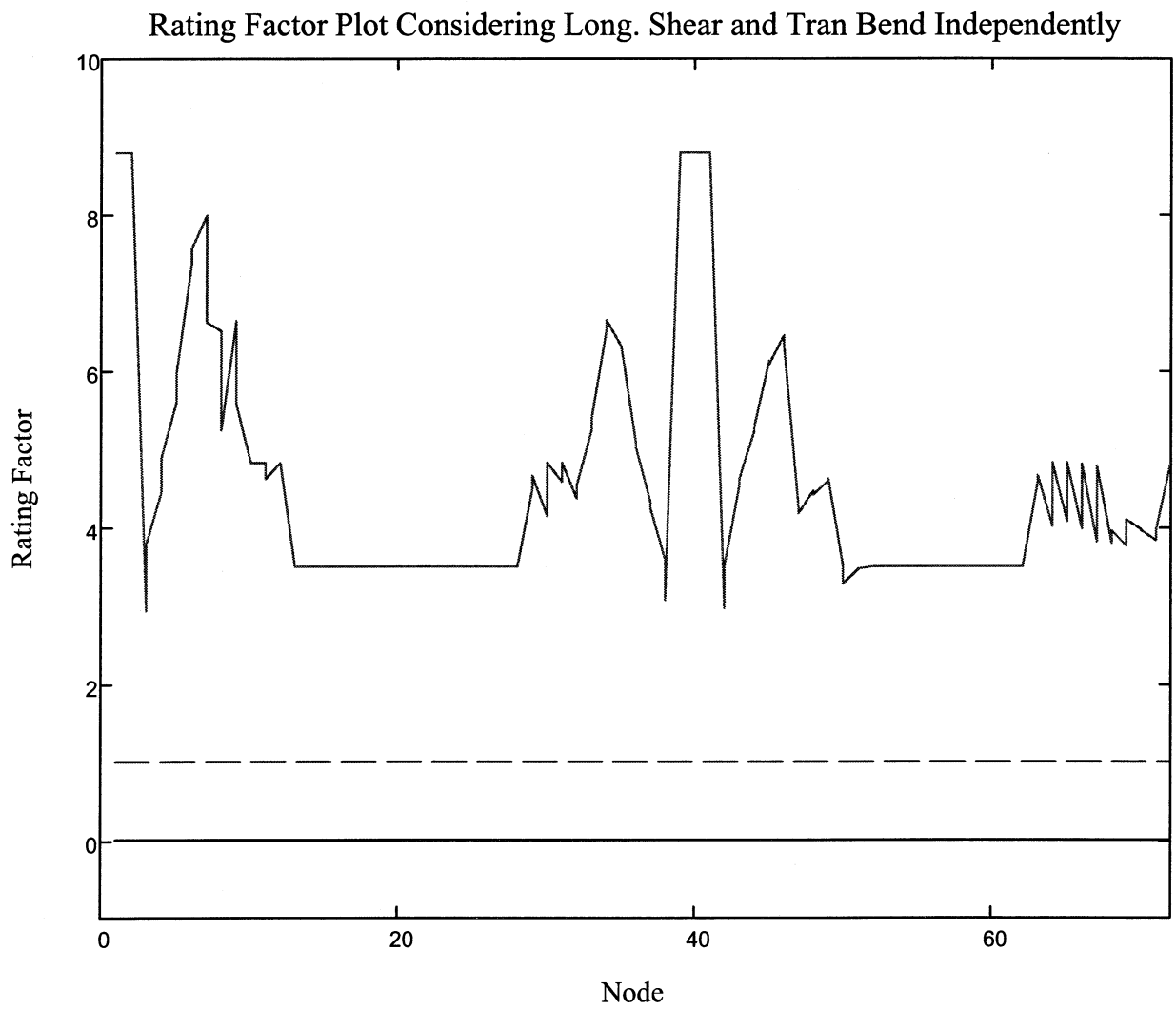
Minimum Rating Factor for Transverse Bending is min[redacted]

URS

Project: Cline--Ramp A Seg 2
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

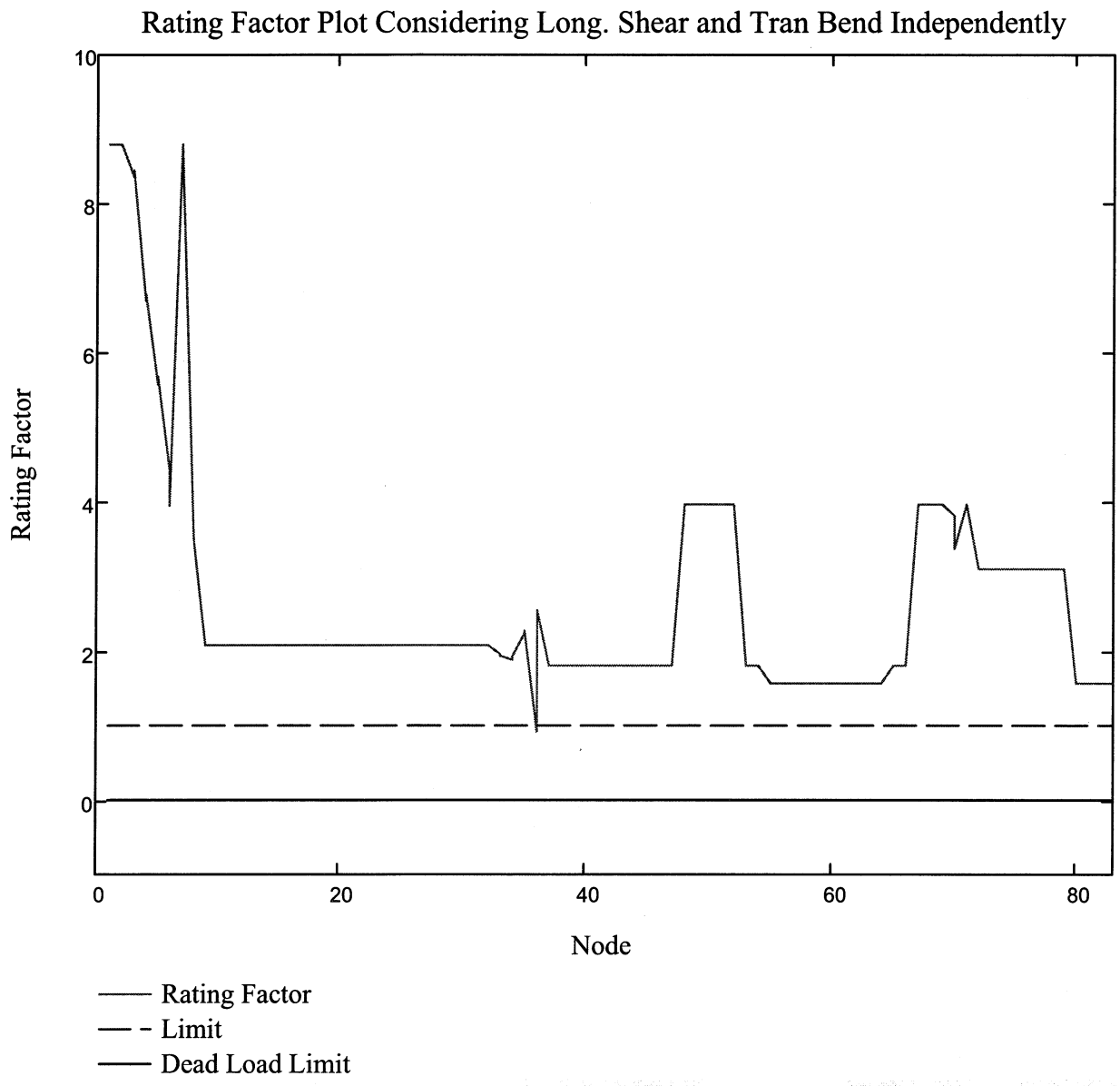



Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.931$ at node $minRF_2 = 3$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

8.5/81

| URS | Job No. 25626272.00001 | Page _____ |
|---|---|---|
| Project: Cline--Ramp A Seg 3 | | |
| Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc | Design: TSP | Date: 6 / 17 / 2009 |
| | Check: Ind Chk | Date: / / |

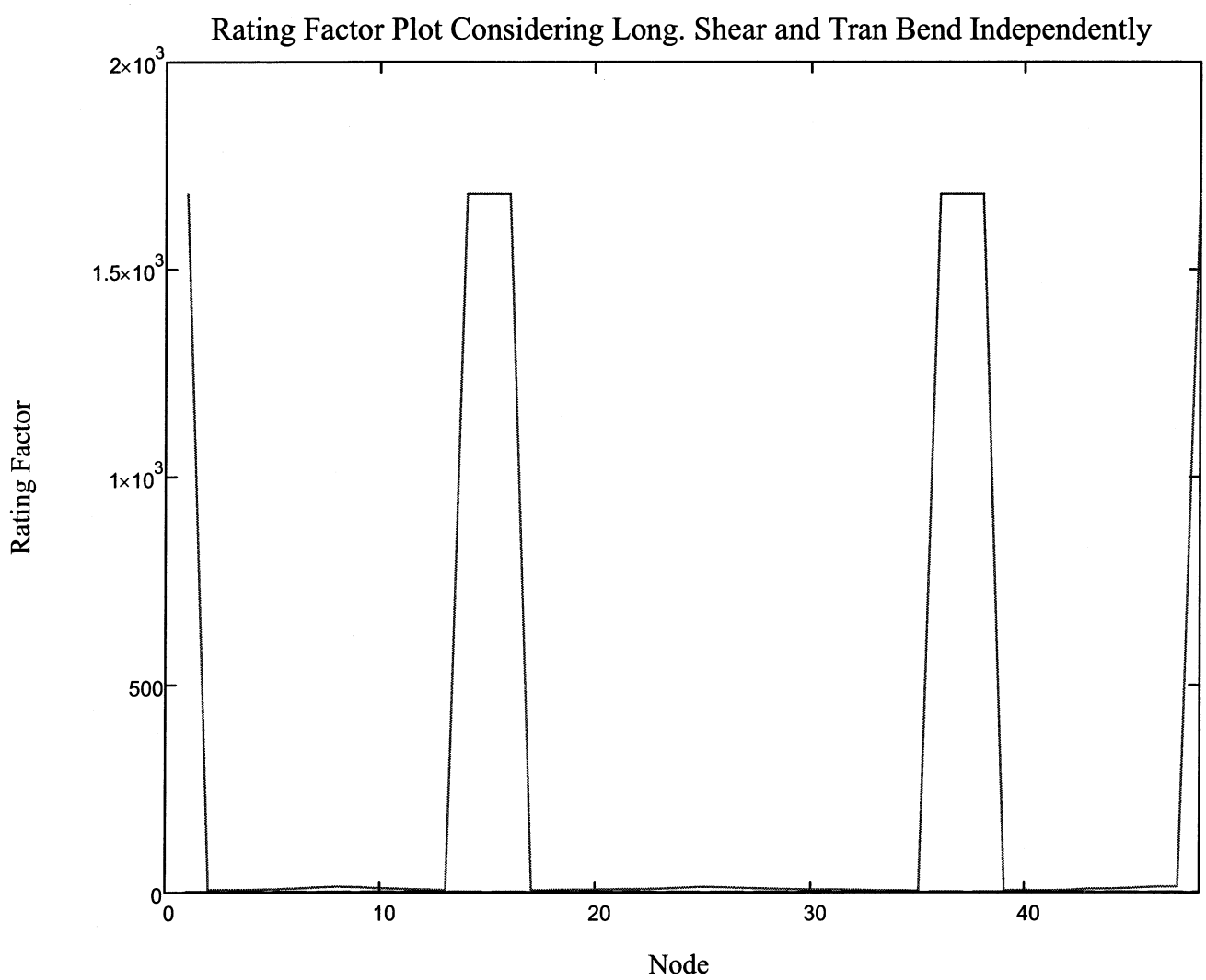



Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.914$ at node $minRF_2 = 36$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

8.5/82

| URS | Job No. 25626272.00001 | Page _____ |
|---|---|---|
| Project: Cline--Ramp B<br>Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc | Design: TSP | Date: 6 / 17 / 2009 |
| | Check: Ind Chk | Date: / / |




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.193$ at node $minRF_2 = 35$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

8.5/83

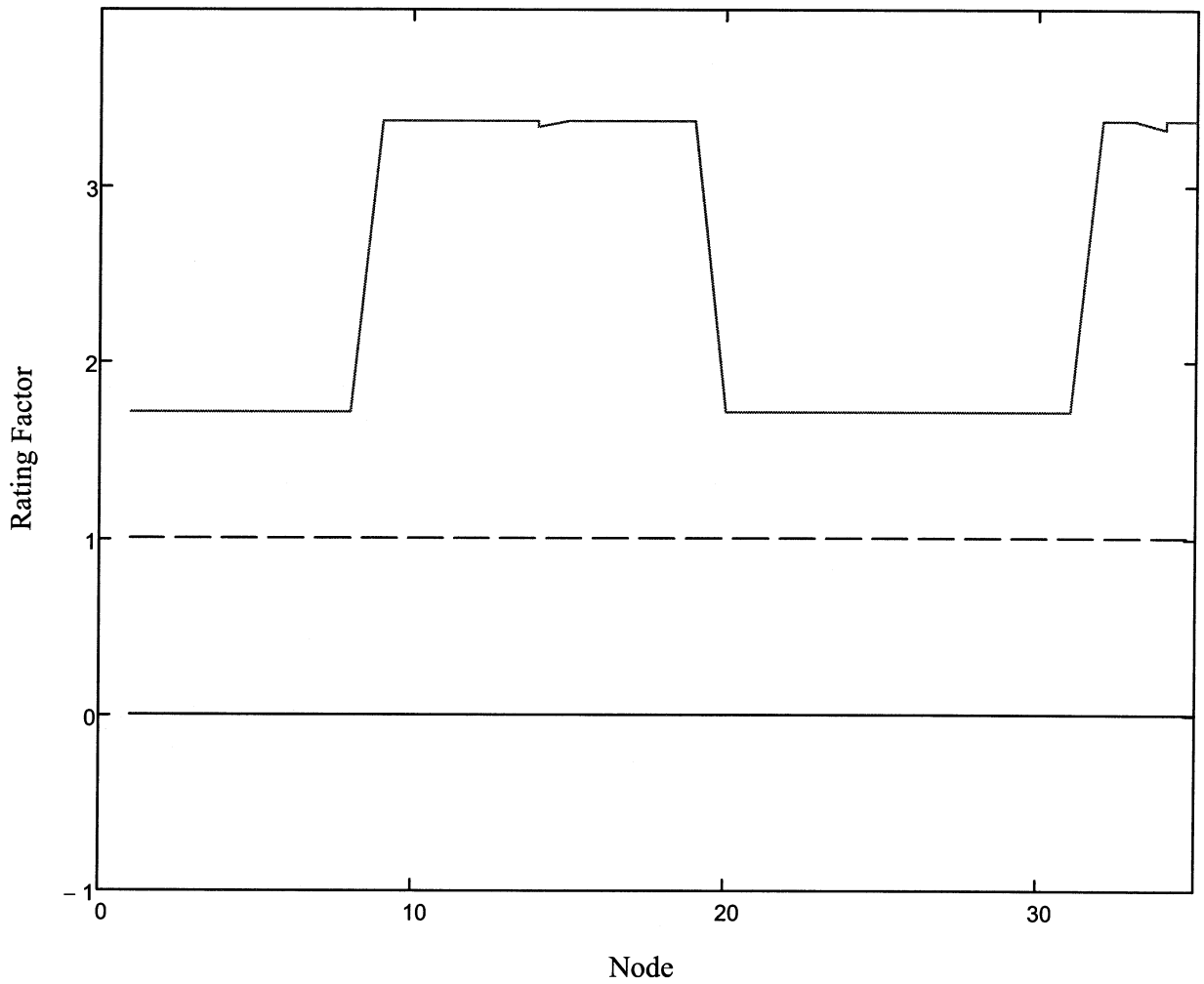
**URS**

Project: Cline--Ramp B Seg 6
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 3.319$ at node $minRF_2 = 34$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

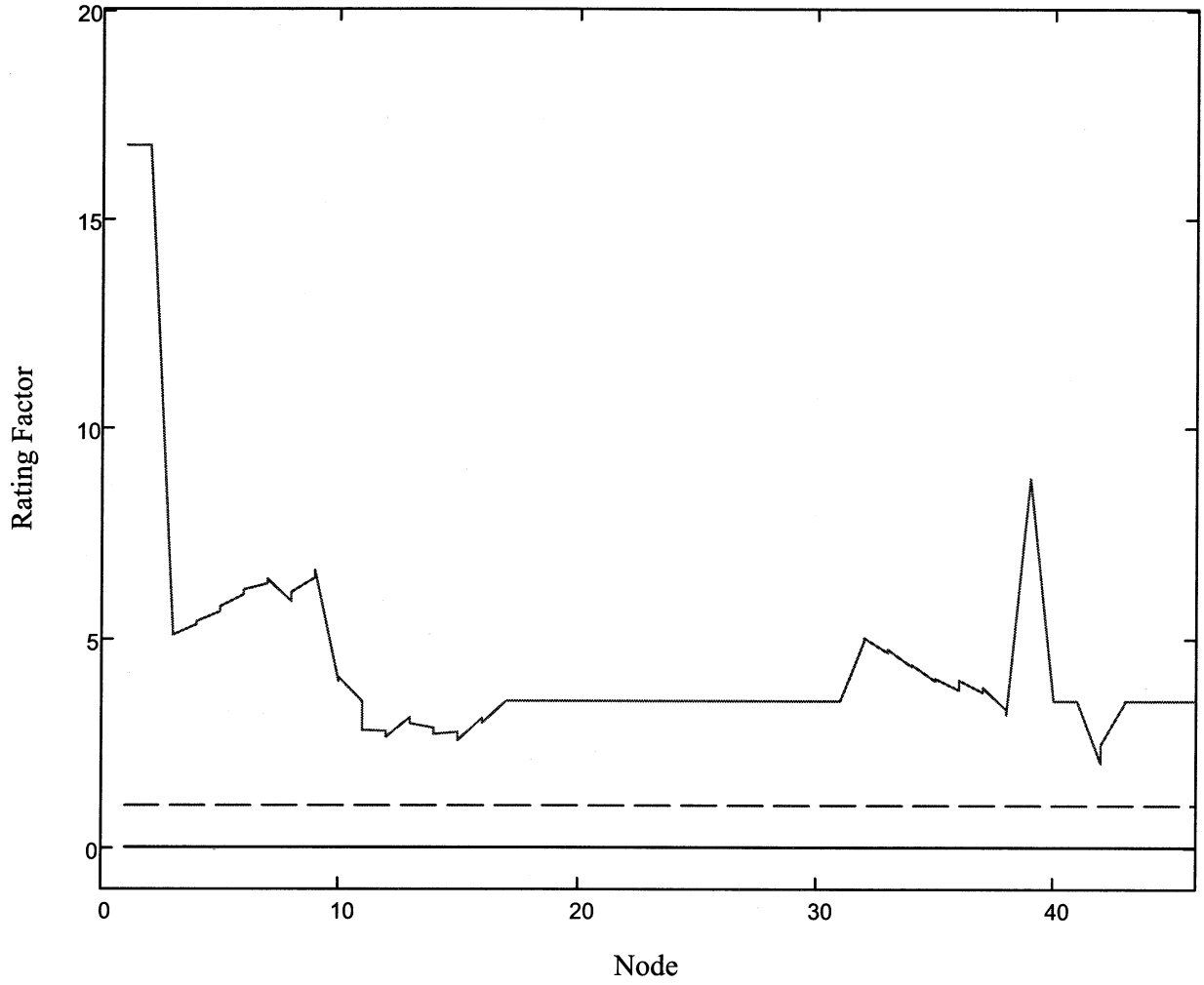
URS

Project: Cline--Ramp C Seg 3
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.005$ at node $minRF_2 = 42$ $minRF_4$ = "Back"

Minimum Rating Factor for Transverse Bending is min[redacted]

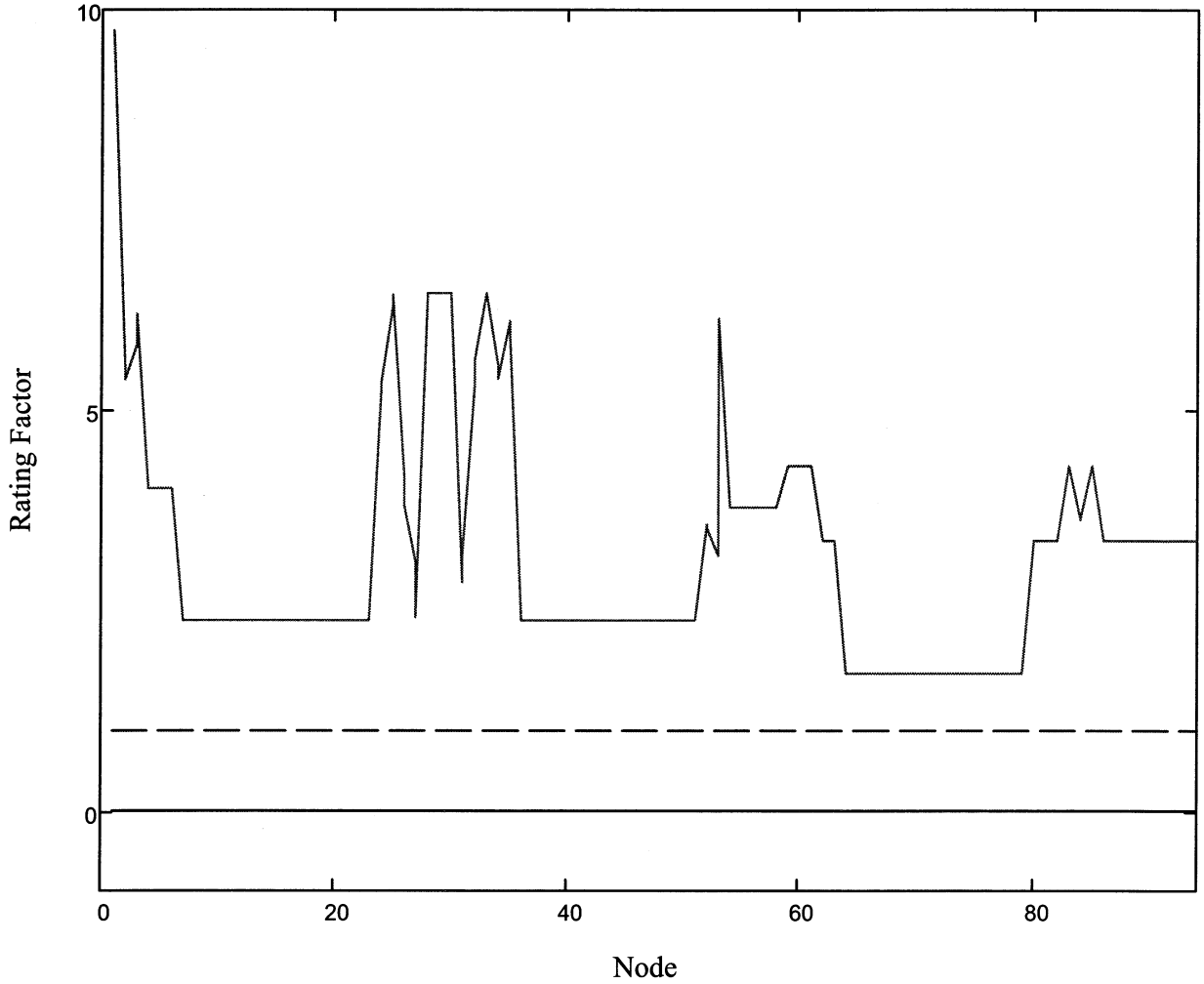
URS

Project: Cline--Ramp C Seg 4
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.417$ at node $minRF_2 = 27$ $minRF_4$ = "Ahead"

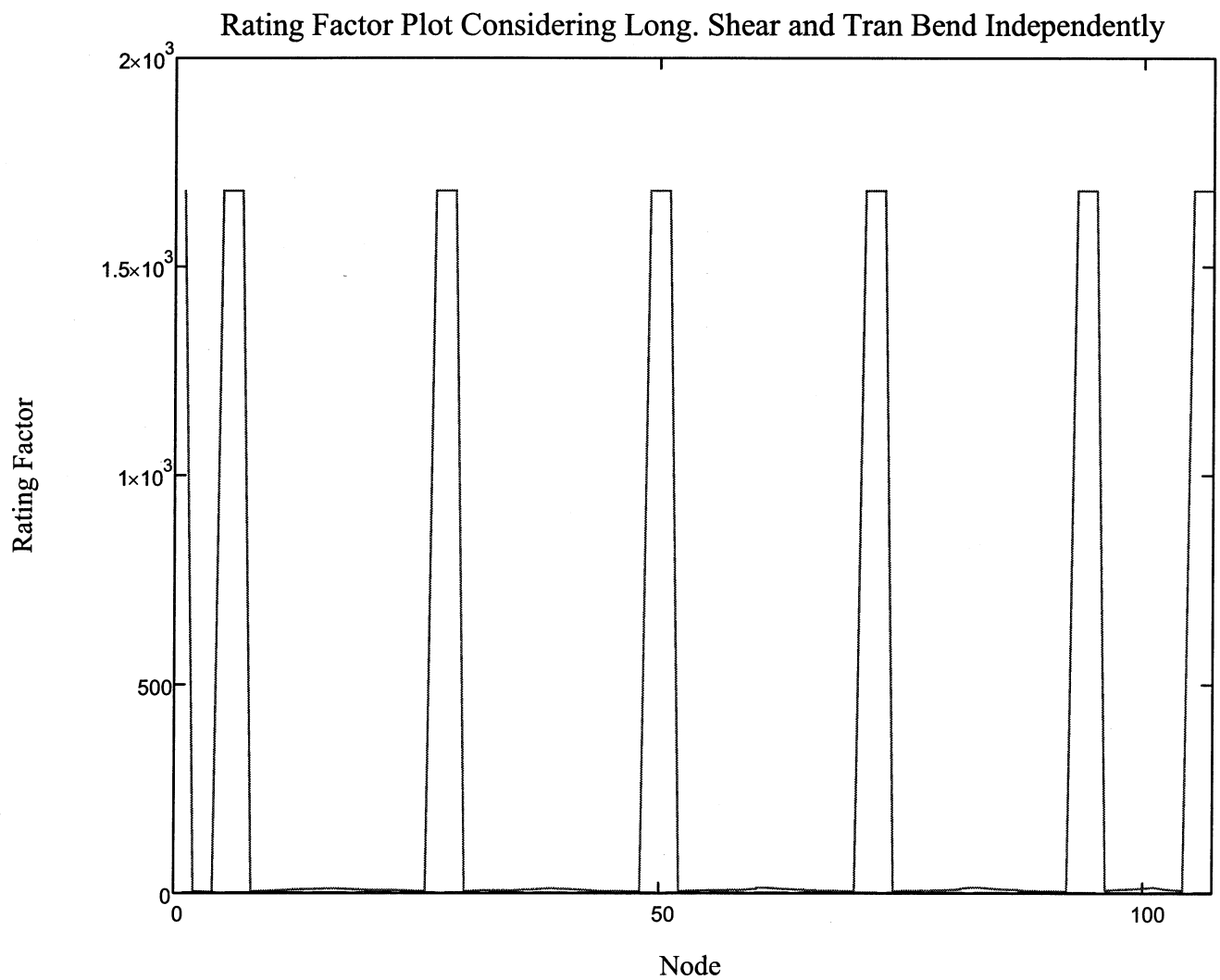
Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp C Units 1 & 6-8
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.242$ at node $minRF_2 = 4$ $minRF_4$ = "Ahead"

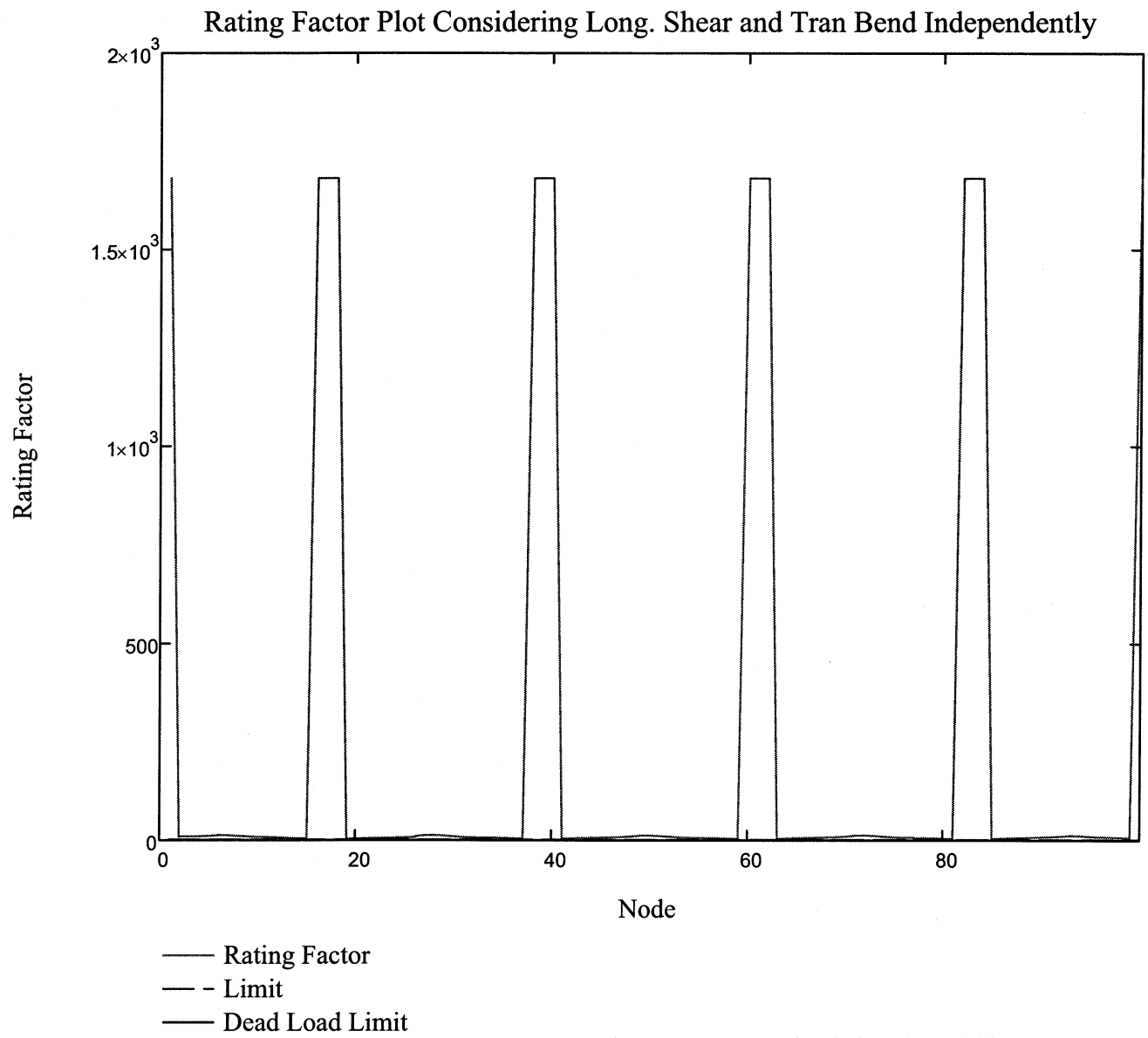
Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

URS

Project: Cline--Ramp C Units 2-5
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

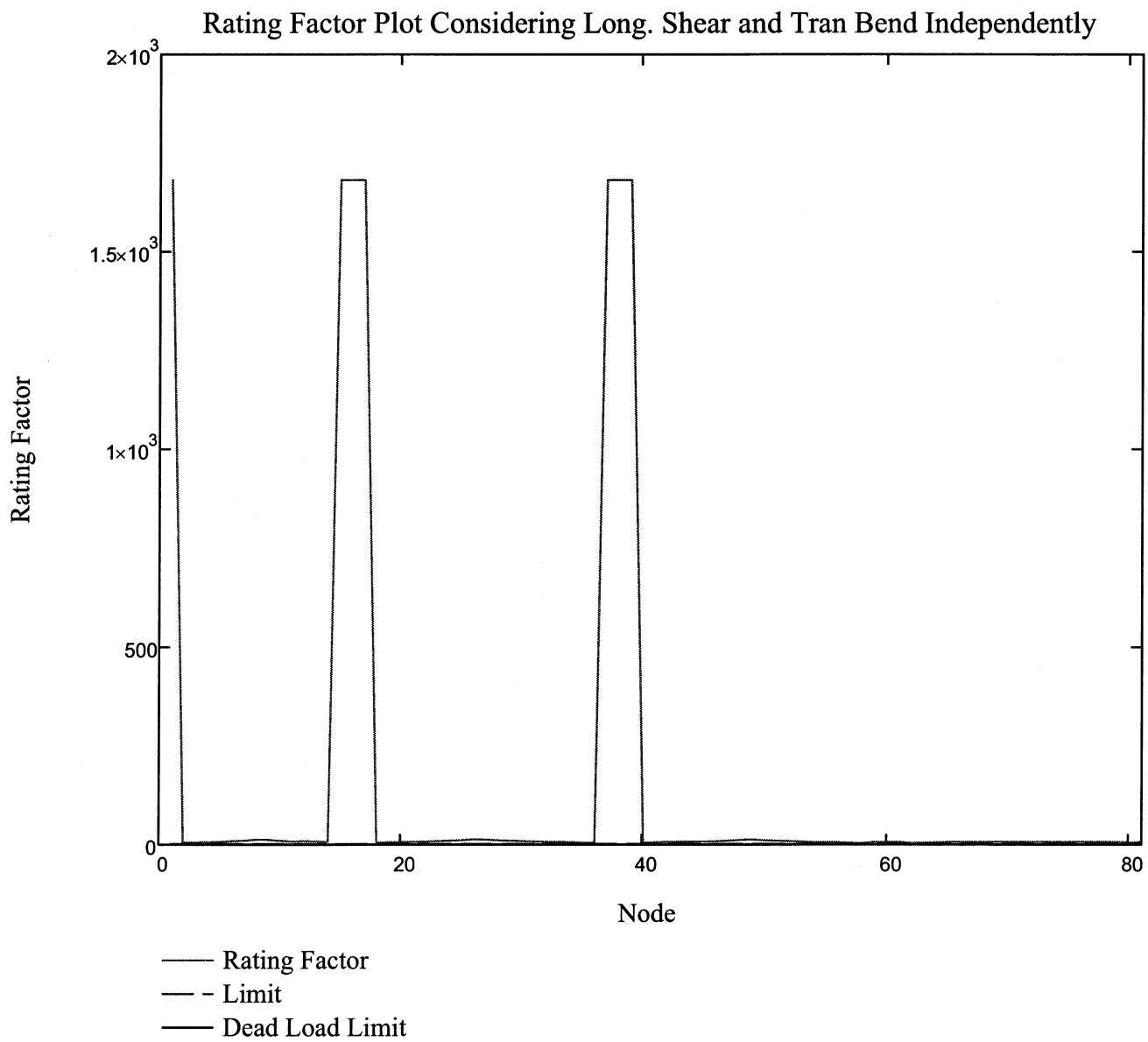



Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.86$ at node $minRF_2 = 19$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

8.5/88

| URS | Job No. 25626272.00001 | Page _____ |
|---|---|---|
| Project: Cline--Ramp D | | |
| Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc | Design: TSP | Date: 6 / 17 / 2009 |
| | Check: Ind Chk | Date: / / |




Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 2.901$ at node $minRF_2 = 58$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ [redacted]

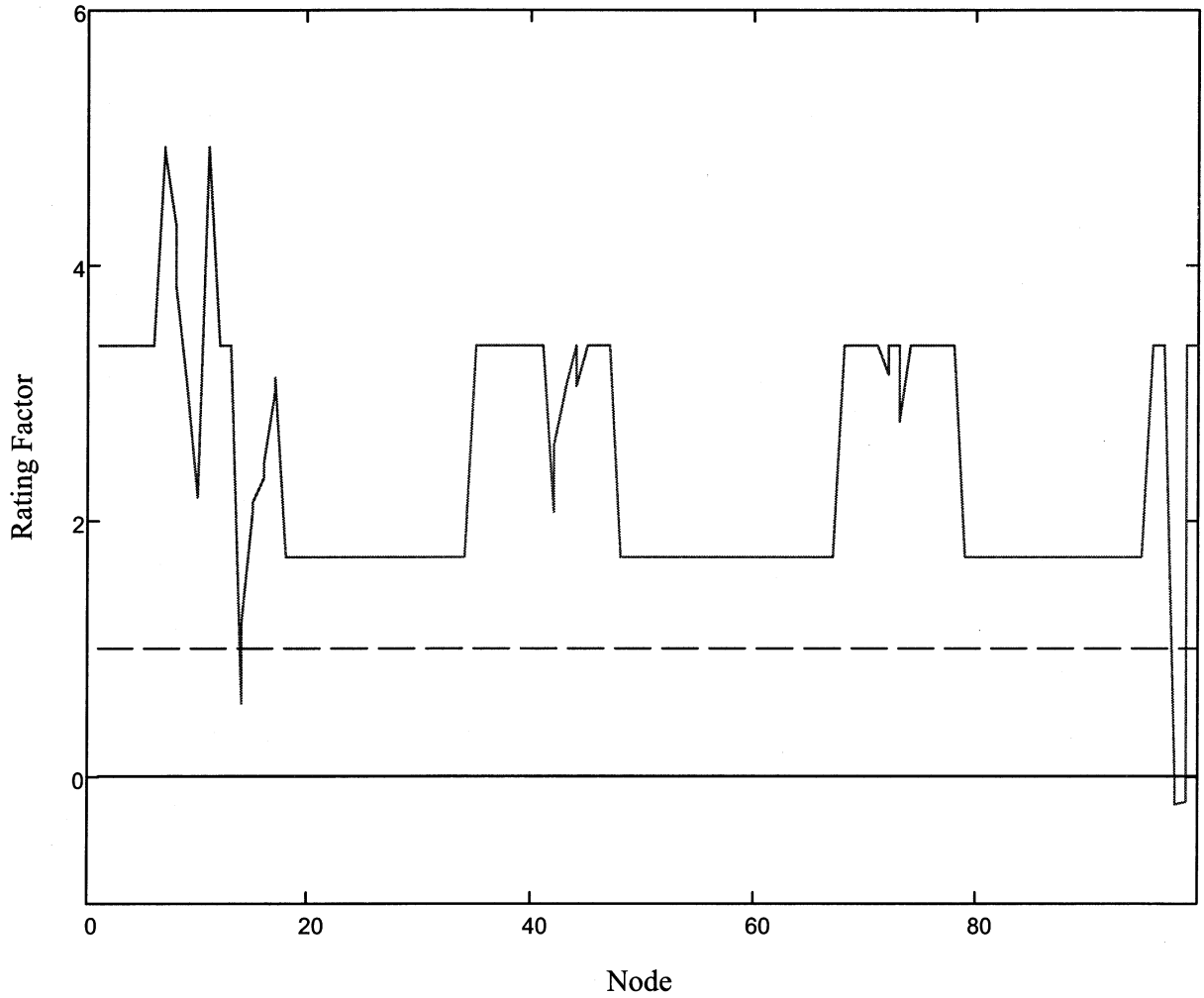
**URS**

Project: Cline--Ramp D Seg 6
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page
Date: 6 / 17 / 2009
Date: / /

Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3$ = [redacted]

85/90

**URS**

Project: Cline--Ramp D Seg 6
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001 | Page _____
Design: TSP | Date: 6 / 17 / 2009
Check: Ind Chk | Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Ramp D Seg 6\

Node := 14 Position := Back $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = -1265 \cdot kips$ | $M_{dc_x} = -41903 \cdot kip \cdot ft$ | $T_{dc_x} = 3550\, ft \cdot kips$ | $N_{dc_x} = -48 \cdot kips$ | Dead Load |
| $V_{dw_x} = -134 \cdot kips$ | $M_{dw_x} = -5743 \cdot kip \cdot ft$ | $T_{dw_x} = -533 \cdot kip \cdot ft$ | $N_{dw_x} = -2 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = -110 \cdot kips$ | $M_{psec_x} = -3288 \cdot kip \cdot ft$ | $T_{psec_x} = 473 \cdot kip \cdot ft$ | $N_{psec_x} = -6 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = 41\, kip$ | $M_{crsh_x} = -1691 \cdot kip \cdot ft$ | $T_{crsh_x} = -797 \cdot kip \cdot ft$ | $N_{crsh_x} = 69 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 58 \cdot kips$ | $M_{LLvmax_x} = 250 \cdot kip \cdot ft$ | $T_{LLvmax_x} = -1192 \cdot kip \cdot f$ | $N_{LLvmax_x} = 12 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -217 \cdot kips$ | $M_{LLvmin_x} = 170 \cdot kip \cdot ft$ | $T_{LLvmin_x} = -969 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 2 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = -137 \cdot kips$ | $M_{LLtmax_x} = 1161 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 1906 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 3 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = -106 \cdot kips$ | $M_{LLtmin_x} = 808 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -2055 \cdot kip \cdot ft$ | $N_{LLtmin_x} = 4 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = 261 \cdot kips$ Primary PT Shear

$N_{prim_x} = -12976 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 35234 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1439 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = -6 \cdot kips$

$M_{tu_x} = -144 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = -93 \cdot kip \cdot ft$

$N_{tu_x} = 0 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 11277 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 17765 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 59.069 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web

$A_{b_x} = 0.162 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.135 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 109.368 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 94 \cdot in$ Depth for Torsion

$A_{s_x} = 6.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = -1793 \cdot kips$ | $T_{uvmax_x} = 2103 \cdot kip \cdot ft$ | $M_{uvmax_x} = -64789\, ft \cdot kips$ | $N_{uvmax_x} = -18 \cdot kips$ |
| $V_{uvmin_x} = -2165 \cdot kips$ | $T_{uvmin_x} = 2404 \cdot kip \cdot ft$ | $M_{uvmin_x} = -64897\, ft \cdot kips$ | $N_{uvmin_x} = -32 \cdot kips$ |
| $V_{utmax_x} = -2057 \cdot kips$ | $T_{utmax_x} = 6286 \cdot kip \cdot ft$ | $M_{utmax_x} = -63559\, ft \cdot kips$ | $N_{utmax_x} = -30 \cdot kips$ |
| $V_{utmin_x} = -2015 \cdot kips$ | $T_{utmin_x} = 938 \cdot kip \cdot ft$ | $M_{utmin_x} = -64036\, ft \cdot kips$ | $N_{utmin_x} = -29 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -1.024\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 7532 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 91.918 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 82.726 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \text{ if } \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \text{ otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00037$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.702 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.65$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 583.095 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -935.875\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 39.15 \cdot kips$

$$RF_{vpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmax_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{vpos_{x,1}} = 2.667$$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$$\varepsilon_{svmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \text{ if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \text{ otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{svmin_x} = -0.00036$$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.752 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.552$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 574.46 \cdot kips$

$$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinShear_x = \text{"Yes"}$

$$V_{dwebvmin_y} := \frac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebvmin_x} = -1.054 \times 10^3\, kip$

$$V_{LLwebvmin_y} := \frac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebvmin_x} = -188.006 \cdot kips$

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$$RF_{vneg} := \text{for } i \in y \;\; \begin{cases} V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)} \\ V_p \leftarrow \left|V_{prim_i}\right| \\ \phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases} \\ RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}} \\ RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases} \\ RF_{i,2} \leftarrow RF_{1_i} \\ RF_{i,3} \leftarrow RF_{2_i} \end{cases}$$

$$RF$$

$$RF_{vneg_{x,1}} = 0.57$$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmax} := \text{for } i \in y \;\; \begin{cases} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \;\; \text{if } \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \;\; \text{otherwise} \end{cases}$$

$$\varepsilon$$

$$\varepsilon_{stmax_x} = -0.00037$$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.712 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.63$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 581.284 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -1.054 \times 10^3 \, kip$

$V_{LLwebtmax_y} := \dfrac{1.35 V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -174.165 \cdot kips$

$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$RF_{tpos_{x,1}} = 0.655$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left| M_{utmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| \left| V_{utmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left| M_{utmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left| \left| V_{utmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{stmin_x} = -0.00037$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.716 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.622$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 580.645 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinTorsion_x = \text{"No"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \begin{cases} \dfrac{T_{vmin_y}\left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if } UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{cases}$$

$V_{dwebtmin_x} = -935.875\,kip$

$$V_{LLwebtmin_y} := \frac{1.35\,V_{LLtmin_y}}{n_{webs_y}} + \begin{cases} \dfrac{T_{vmin_y}\left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if } UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{cases}$$

$V_{LLwebtmin_x} = -71.55 \cdot kips$

$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 2.667}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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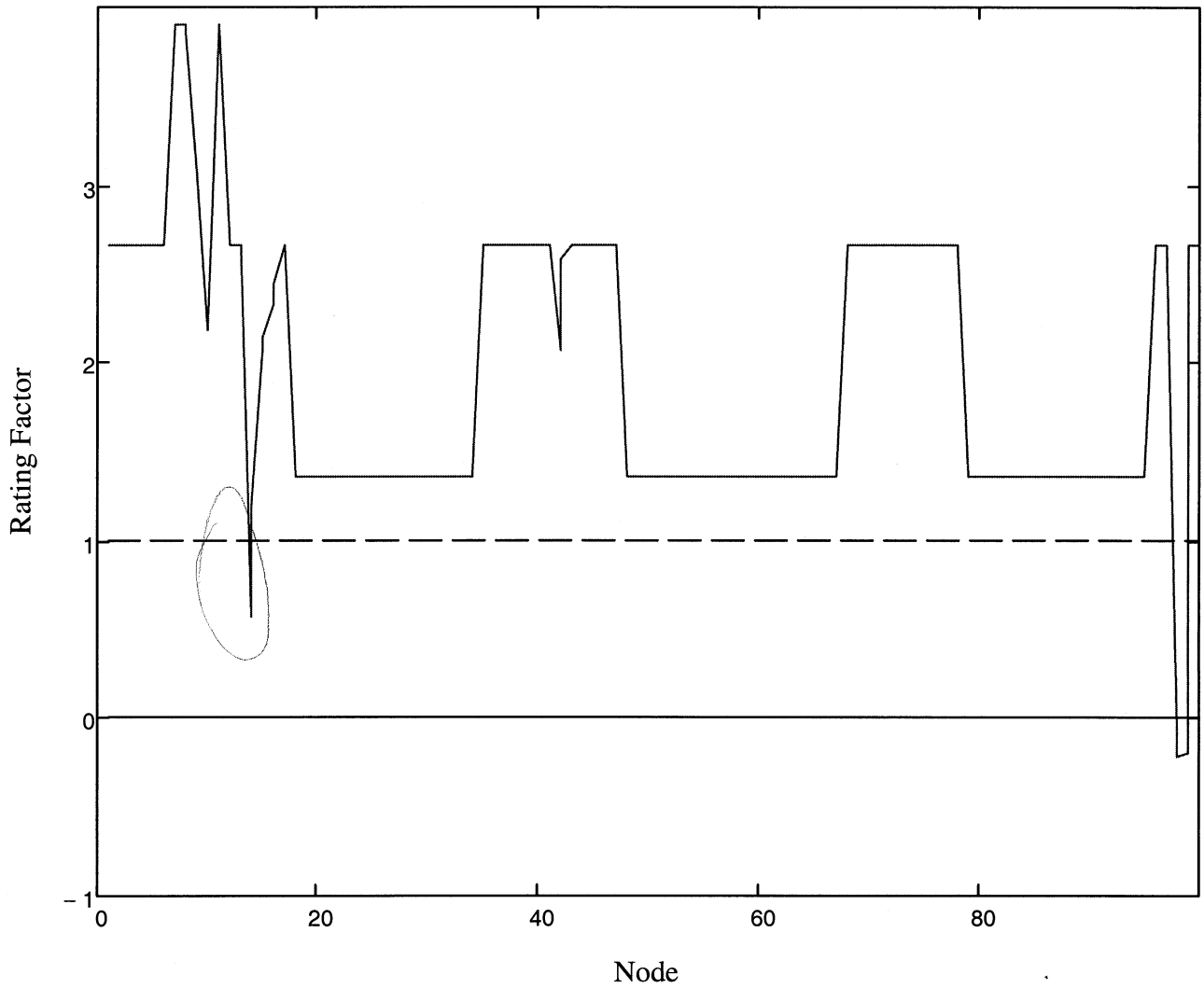
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— – Limit
—— Dead Load Limit

Due to PT being ignored out. Ignore this point

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3 = 1.358$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 107.094 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 23.483 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.19 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.041 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 13.592 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.754 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 293.059 \cdot kips$

$\phi V_{n2_y} := \phi \cdot (V_{cvmax_y} + V_{s2_y} + |V_{p_y}|)$ $\qquad \phi V_{n2_x} = 905.989 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 584.863 \cdot kips$

$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\qquad \phi V_{n_3} = 1.169 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.873 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.754 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_n \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow |V_d| \\ V_{u_{i+1}} \leftarrow |V_d + V_{LL}| \end{array} \right. \\ V_u \end{array} \right.$$

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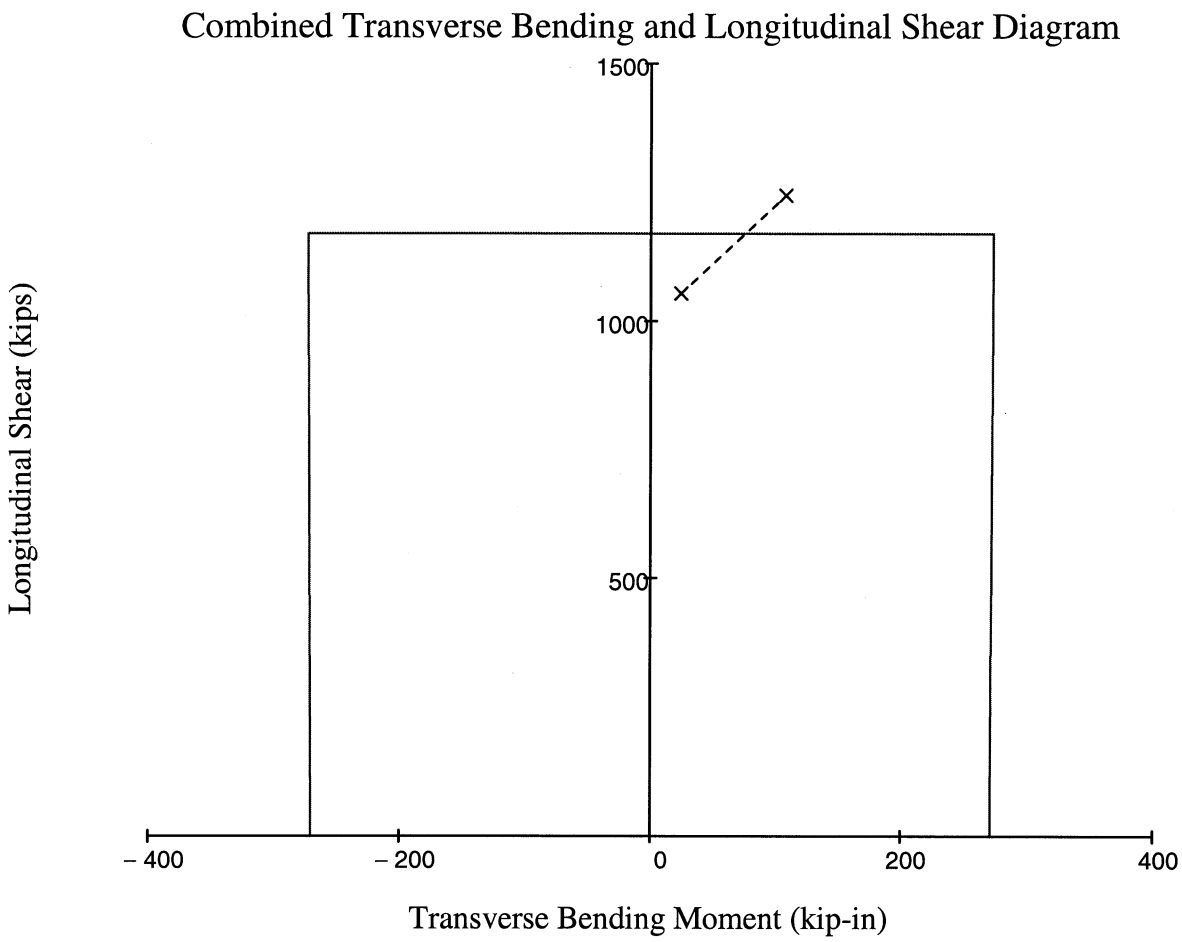


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.985$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 0.611$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 0.66$

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Node := 15 Position := Back $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = -1162 \cdot kips$ | $M_{dc_x} = -31993 \cdot kip \cdot ft$ | $T_{dc_x} = 3464\, ft \cdot kips$ | $N_{dc_x} = -180 \cdot kips$ | Dead Load |
| $V_{dw_x} = -124 \cdot kips$ | $M_{dw_x} = -4723 \cdot kip \cdot ft$ | $T_{dw_x} = -510 \cdot kip \cdot ft$ | $N_{dw_x} = -8 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = -109 \cdot kips$ | $M_{psec_x} = -2377 \cdot kip \cdot ft$ | $T_{psec_x} = 467 \cdot kip \cdot ft$ | $N_{psec_x} = -22 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = 39\, kip$ | $M_{crsh_x} = -2757 \cdot kip \cdot ft$ | $T_{crsh_x} = -1062 \cdot kip \cdot ft$ | $N_{crsh_x} = 273 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 65 \cdot kips$ | $M_{LLvmax_x} = 265 \cdot kip \cdot ft$ | $T_{LLvmax_x} = -1309 \cdot kip \cdot f$ | $N_{LLvmax_x} = 44 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -192 \cdot kips$ | $M_{LLvmin_x} = 1493 \cdot kip \cdot ft$ | $T_{LLvmin_x} = -1093 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 13 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = -126 \cdot kips$ | $M_{LLtmax_x} = 1984 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 1797 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 6 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = -101 \cdot kips$ | $M_{LLtmin_x} = 1534 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -2078 \cdot kip \cdot ft$ | $N_{LLtmin_x} = 20 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = 600 \cdot kips$ Primary PT Shear

$N_{prim_x} = -12982 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 31137 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1598 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = -7 \cdot kips$

$M_{tu_x} = -99 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = -97 \cdot kip \cdot ft$

$N_{tu_x} = 2 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 10895 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 17962 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 60.318 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 9 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web

$A_{b_x} = 0.162 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.135 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 109.368 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 95 \cdot in$ Depth for Torsion

$A_{s_x} = 6.6 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.75 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = -1640 \cdot kips$ | $T_{uvmax_x} = 1734 \cdot kip \cdot ft$ | $M_{uvmax_x} = -50474\, ft \cdot kips$ | $N_{uvmax_x} = -63 \cdot kips$ |
| $V_{uvmin_x} = -1987 \cdot kips$ | $T_{uvmin_x} = 2025 \cdot kip \cdot ft$ | $M_{uvmin_x} = -48816\, ft \cdot kips$ | $N_{uvmin_x} = -105 \cdot kips$ |
| $V_{utmax_x} = -1898 \cdot kips$ | $T_{utmax_x} = 5927 \cdot kip \cdot ft$ | $M_{utmax_x} = -48153\, ft \cdot kips$ | $N_{utmax_x} = -114 \cdot kips$ |
| $V_{utmin_x} = -1864 \cdot kips$ | $T_{utmin_x} = 696 \cdot kip \cdot ft$ | $M_{utmin_x} = -48760\, ft \cdot kips$ | $N_{utmin_x} = -96 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -1.047\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 7615 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 89.413 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 80.471 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0004$

$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 584.855 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = -864\ kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 43.875 \cdot kips$

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$$RF_{vpos} := \text{for } i \in y \;\; \begin{array}{l} V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})} \\ V_p \leftarrow \left| V_{prim_i} \right| \\ \phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases} \\ RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}} \\ RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases} \\ RF_{i,2} \leftarrow RF_{1_i} \\ RF_{i,3} \leftarrow RF_{2_i} \end{array}$$

$$RF$$

$$RF_{vpos_{x,1}} = 2.667$$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$$\varepsilon_{svmin} := \text{for } i \in y \;\; \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left| M_{uvmin_i} \right|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| \left| V_{uvmin_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \;\; \text{if } \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \;\; \text{otherwise} \end{array}$$

$$\varepsilon$$

$$\varepsilon_{svmin_x} = -0.0004$$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 584.855 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = -864\ kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -129.6 \cdot kips$

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$$RF_{vneg} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmin_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{vneg_{x,1}} = 2.667$$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmax} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left||V_{utmax_i}| - |V_{prim_i}|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left||V_{utmax_i}| - |V_{prim_i}|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{stmax_x} = -0.0004$$

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$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 584.855 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = -975.1\,kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -162.034 \cdot kips$

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$$RF_{tpos} := \text{for } i \in y \;\; \begin{array}{l} V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ V_p \leftarrow \left|V_{prim_i}\right| \\ \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases} \\ RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{cases} \\ RF_{i,2} \leftarrow RF_{1_i} \\ RF_{i,3} \leftarrow RF_{2_i} \end{array} \;\; RF$$

$$RF_{tpos_{x,1}} = 2.077$$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \text{for } i \in y \;\; \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \;\; \text{if } \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \;\; \text{otherwise} \end{array} \;\; \varepsilon$$

$$\varepsilon_{stmin_x} = -0.0004$$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 584.855 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left| T_{utmin_i} \right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$\boxed{UseTorsionMinTorsion_x = \text{"No"}}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left| T_{utmin_y} - 1.35 \cdot T_{LLtmin_y} \right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebtmin_x} = -864\ kip$

$$V_{LLwebtmin_y} := \frac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left| 1.35 \cdot T_{LLtmin_y} \cdot d_{t_y} \right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebtmin_x} = -68.175 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 2.667}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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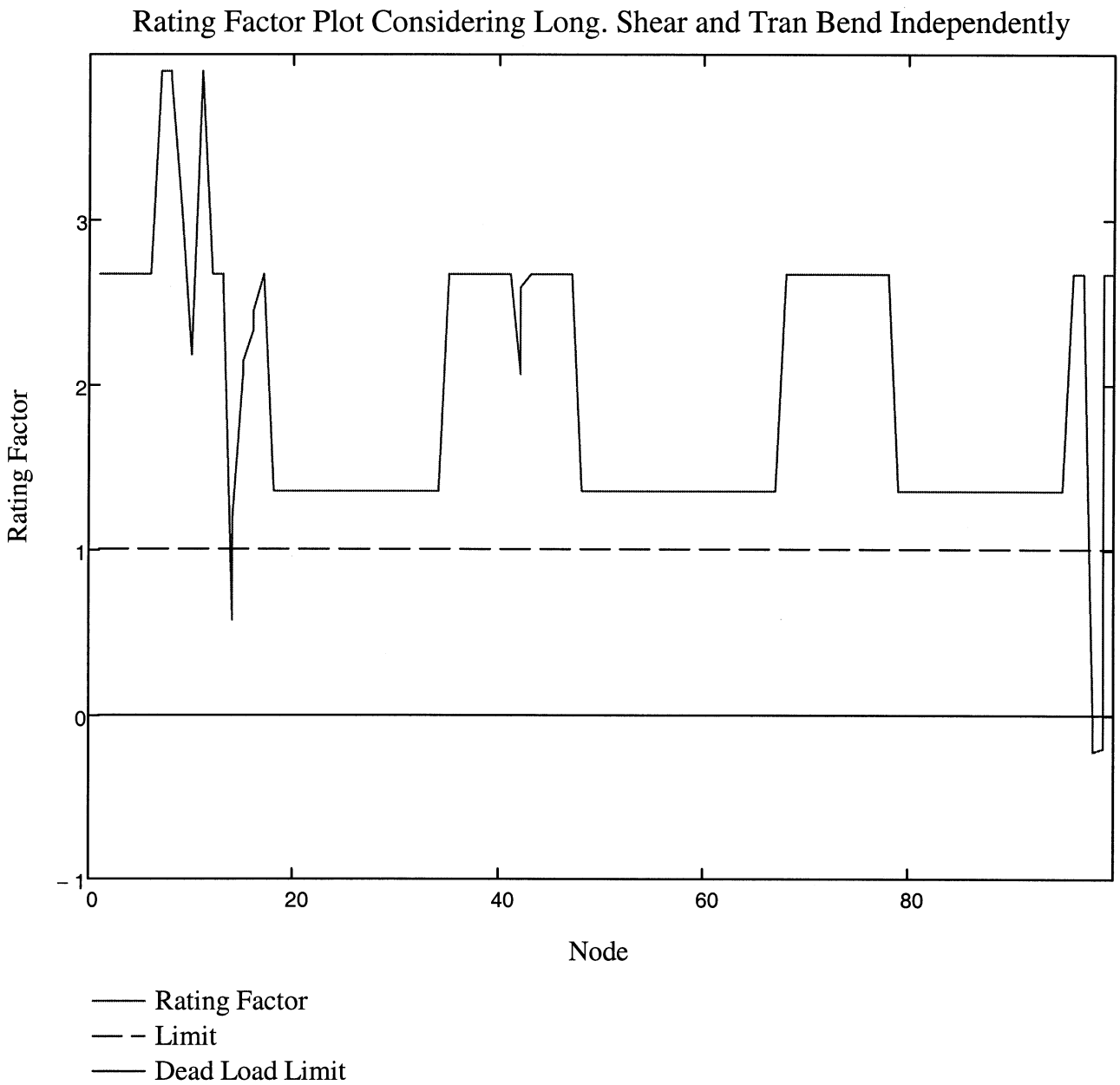


Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 1.358$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 107.094 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 23.483 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.19 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.041 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 13.592 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.754 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 286.305 \cdot kips$

$\phi V_{n2_y} := \phi \cdot (V_{cvmax_y} + V_{s2_y} + |V_{p_y}|)$ $\qquad \phi V_{n2_x} = 1.054 \times 10^3 \cdot kip$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 572.611 \cdot kips$

$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\qquad \phi V_{n_3} = 1.312 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.875 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.754 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_n \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow |V_d| \\ V_{u_{i+1}} \leftarrow |V_d + V_{LL}| \end{array} \right. \\ V_u \end{array} \right.$$

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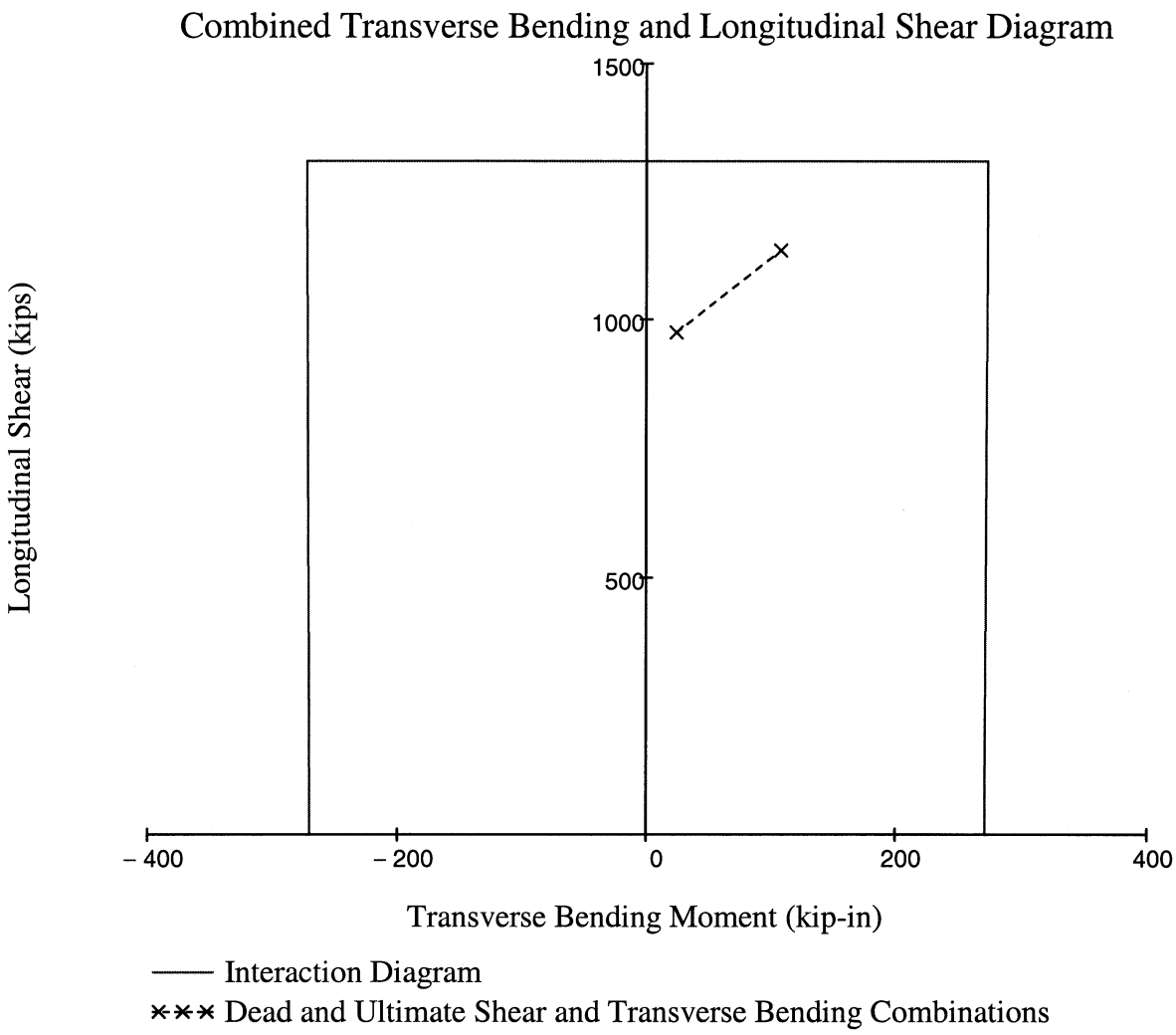


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.985$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 3.455$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 2.077$

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Node := 97 Position := Back $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = 408 \cdot kips$ | $M_{dc_x} = 4700 \cdot kip \cdot ft$ | $T_{dc_x} = 726\, ft \cdot kips$ | $N_{dc_x} = 1 \cdot kips$ | Dead Load |
| $V_{dw_x} = 52 \cdot kips$ | $M_{dw_x} = 542 \cdot kip \cdot ft$ | $T_{dw_x} = 185 \cdot kip \cdot ft$ | $N_{dw_x} = -2 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = 32 \cdot kips$ | $M_{psec_x} = 329 \cdot kip \cdot ft$ | $T_{psec_x} = 485 \cdot kip \cdot ft$ | $N_{psec_x} = 0 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = 12\, kip$ | $M_{crsh_x} = -1859 \cdot kip \cdot ft$ | $T_{crsh_x} = -856 \cdot kip \cdot ft$ | $N_{crsh_x} = 571 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 195 \cdot kips$ | $M_{LLvmax_x} = 1010 \cdot kip \cdot ft$ | $T_{LLvmax_x} = 283 \cdot kip \cdot ft$ | $N_{LLvmax_x} = 12 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -39 \cdot kips$ | $M_{LLvmin_x} = 896 \cdot kip \cdot ft$ | $T_{LLvmin_x} = -440 \cdot kip \cdot ft$ | $N_{LLvmin_x} = -23 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = 143 \cdot kips$ | $M_{LLtmax_x} = 590 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 970 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 0 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = 4 \cdot kips$ | $M_{LLtmin_x} = 1426 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -899 \cdot kip \cdot ft$ | $N_{LLtmin_x} = 7 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = -322 \cdot kips$ Primary PT Shear

$N_{prim_x} = -5660 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = -3262 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 477 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = 7 \cdot kips$

$M_{tu_x} = 245 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = 124 \cdot kip \cdot ft$

$N_{tu_x} = -46 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 7371 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 19143 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 66.947 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web

$A_{b_x} = 0.162 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.135 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 40.362 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 101 \cdot in$ Depth for Torsion

$A_{s_x} = 7.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.25 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

### Operating Load Combinations:

### Maximum and Corresponding Shear Combinations:

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

### Maximum and Corresponding Torsion Combinations:

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

### Corresponding Moment Combinations:

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

### Corresponding Axial Force Combinations:

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = 889 \cdot kips$ ? | $T_{uvmax_x} = 1624 \cdot kip \cdot ft$ | $M_{uvmax_x} = 7451\ ft \cdot kips$ ? | $N_{uvmax_x} = 300 \cdot kips$ |
| $V_{uvmin_x} = 573 \cdot kips$ | $T_{uvmin_x} = 648 \cdot kip \cdot ft$ | $M_{uvmin_x} = 7297\ ft \cdot kips$ | $N_{uvmin_x} = 253 \cdot kips$ |
| $V_{utmax_x} = 819 \cdot kips$ | $T_{utmax_x} = 2552 \cdot kip \cdot ft$ | $M_{utmax_x} = 6884\ ft \cdot kips$ | $N_{utmax_x} = 284 \cdot kips$ |
| $V_{utmin_x} = 631 \cdot kips$ | $T_{utmin_x} = 28 \cdot kip \cdot ft$ | $M_{utmin_x} = 8013\ ft \cdot kips$ | $N_{utmin_x} = 293 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.703\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 4960 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 62.455 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 77.76 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.00035$

$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.769 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.521$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 537.418 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \text{ if } \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \text{ otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"Yes"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \text{ if } UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \text{ otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 352.317\, kip$

$V_{LLwebvmax_y} := \dfrac{1.35\, V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \text{ if } UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \text{ otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 143.719 \cdot kips$

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$RF_{vpos} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{vpos_{x,1}} = 2.667$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$\varepsilon_{svmin} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$\varepsilon$

$\varepsilon_{svmin_x} = -0.00037$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.691 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.671$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 549.847 \cdot kips$

$$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinShear_x = \text{"No"}$

$$V_{dwebvmin_y} := \frac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$$

$V_{dwebvmin_x} = 313\,kip$

$$V_{LLwebvmin_y} := \frac{1.35\,V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$$

$V_{LLwebvmin_y} = -26.325 \cdot kips$

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$RF_{vneg} :=$ for $i \in y$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmin_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \frac{V_p}{n_{webs_i}}\right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

RF

$RF_{vneg_{x,1}} = 2.667$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$\varepsilon_{stmax} :=$ for $i \in y$

$$\varepsilon_1 \leftarrow \frac{\left(\frac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left||V_{utmax_i}| - |V_{prim_i}|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left(\frac{|M_{utmax_i}|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left||V_{utmax_i}| - |V_{prim_i}|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$\varepsilon$

$\varepsilon_{stmax_x} = -0.00036$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.733 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.589$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 543.02 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 352.317\ kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 137.979 \cdot kips$

$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$RF_{tpos_{x,1}} = 2.667$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{stmin_x} = -0.00036$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.731 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.592$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 543.319 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinTorsion_x = \text{"No"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebtmin_x} = 313\,kip$

$$V_{LLwebtmin_y} := \frac{1.35\,V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebtmin_x} = 2.7 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 2.667}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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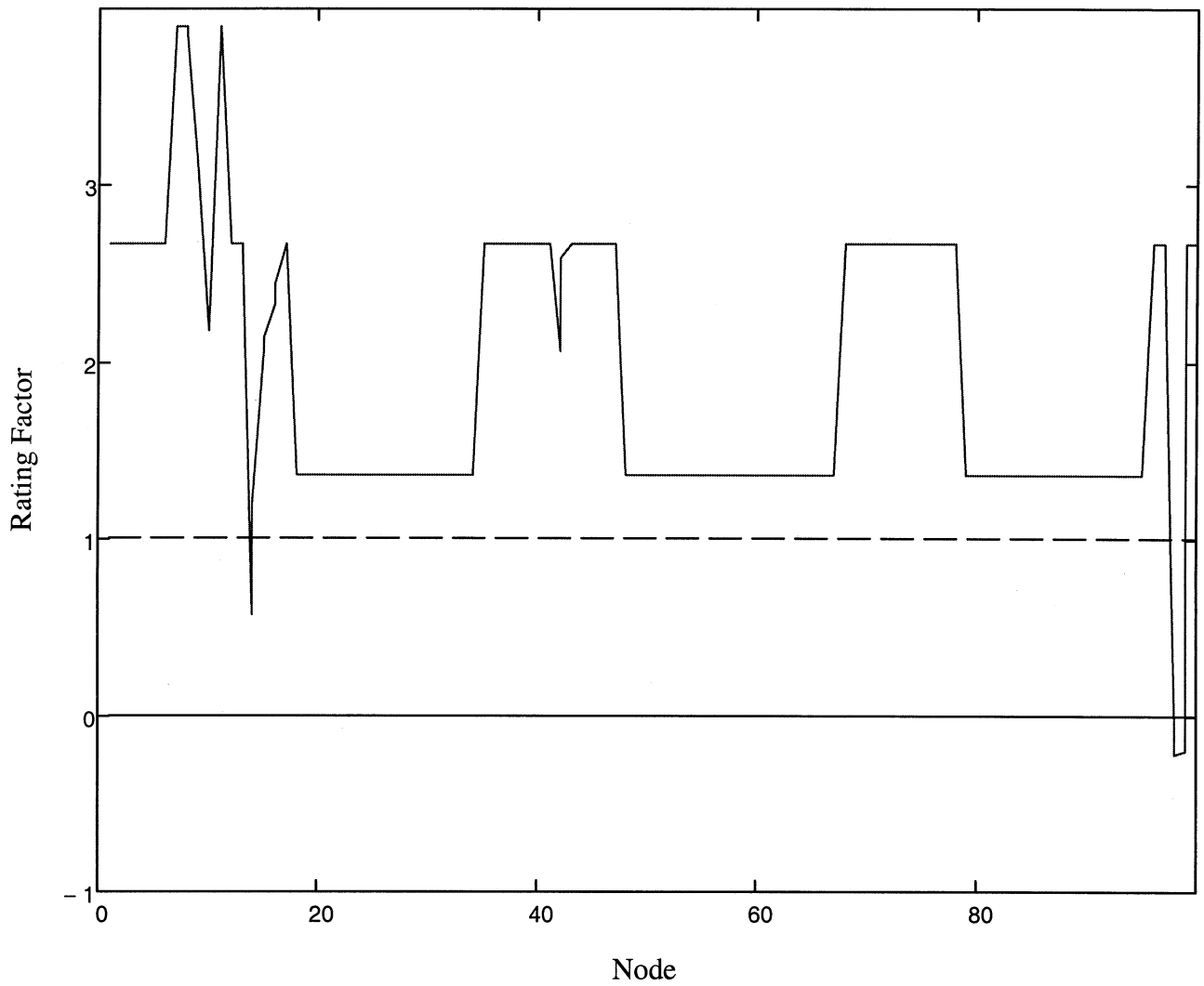
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— – Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4 = \text{"Ahead"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 1.358$

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## Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently

### Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 107.094 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 23.483 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.19 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.041 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 13.592 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.754 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 274.687 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 875.795 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 551.185 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.125 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.878 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.754 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_n \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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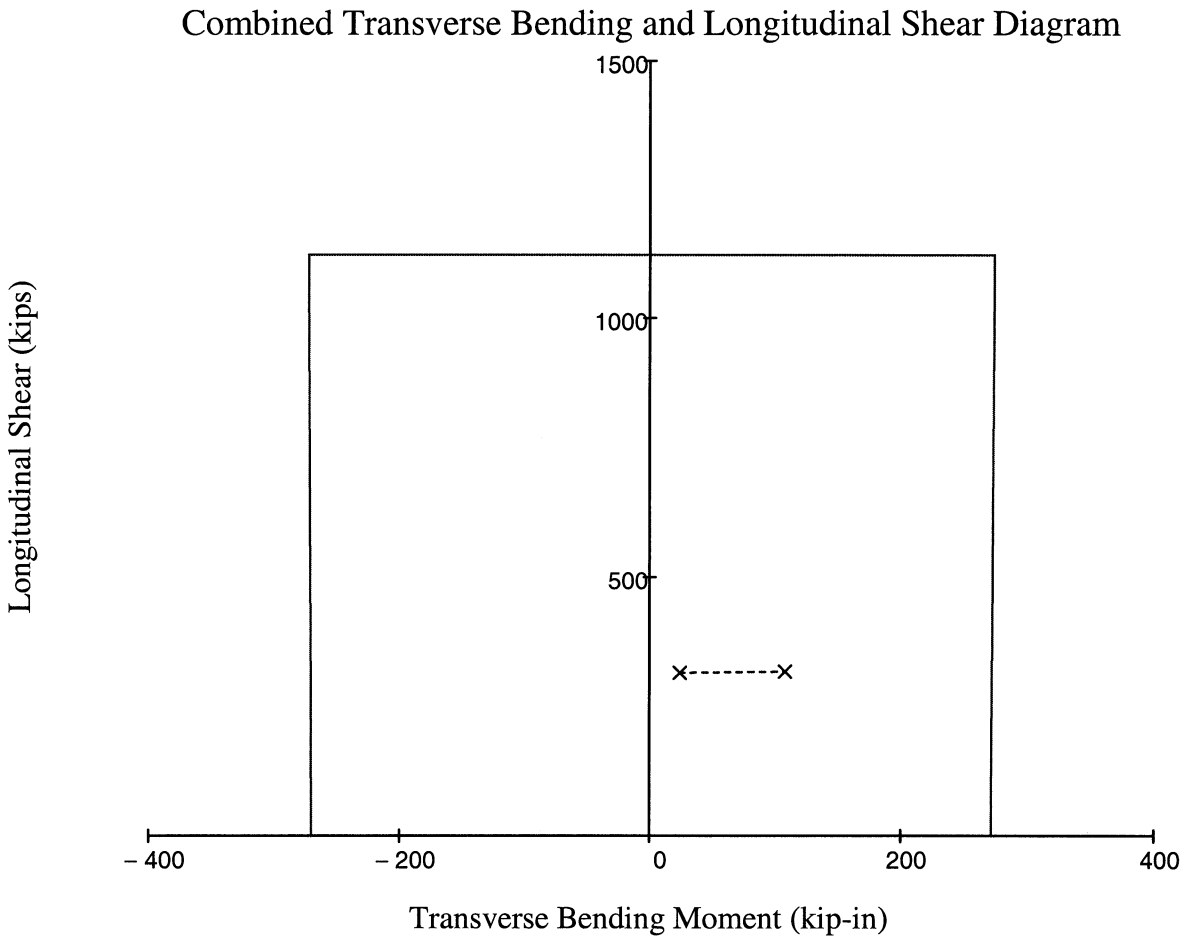


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.985$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 5.374$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 5.597$

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Node := 98 Position := Ahead $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = 489 \cdot kips$ | $M_{dc_x} = 368 \cdot kip \cdot ft$ | $T_{dc_x} = 571\, ft \cdot kips$ | $N_{dc_x} = -1 \cdot kips$ | Dead Load |
| $V_{dw_x} = 57 \cdot kips$ | $M_{dw_x} = 21 \cdot kip \cdot ft$ | $T_{dw_x} = 210 \cdot kip \cdot ft$ | $N_{dw_x} = -1 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = 32 \cdot kips$ | $M_{psec_x} = 25 \cdot kip \cdot ft$ | $T_{psec_x} = 464 \cdot kip \cdot ft$ | $N_{psec_x} = 0 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = 83\, kip$ | $M_{crsh_x} = 214 \cdot kip \cdot ft$ | $T_{crsh_x} = -446 \cdot kip \cdot ft$ | $N_{crsh_x} = -97 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 357 \cdot kips$ | $M_{LLvmax_x} = 71 \cdot kip \cdot ft$ | $T_{LLvmax_x} = -1120 \cdot kip \cdot ft$ | $N_{LLvmax_x} = -3 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -343 \cdot kips$ | $M_{LLvmin_x} = 6 \cdot kip \cdot ft$ | $T_{LLvmin_x} = 2291 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 3 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = -325 \cdot kips$ | $M_{LLtmax_x} = 8 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 2299 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 3 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = 338 \cdot kips$ | $M_{LLtmin_x} = 59 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -1157 \cdot kip \cdot ft$ | $N_{LLtmin_x} = -3 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = 0 \cdot kips$ Primary PT Shear

$N_{prim_x} = 0 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = 0 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 0 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = -50 \cdot kips$

$M_{tu_x} = 97 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = -3113 \cdot kip \cdot ft$

$N_{tu_x} = -48 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 7368 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 19143 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 2$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 66.928 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web

$A_{b_x} = 0.162 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.135 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.035 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 0 \cdot in^2$ ? Area of Post-Tensioning Steel

$d_{t_x} = 101 \cdot in$ Depth for Torsion

$A_{s_x} = 7.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 105.25 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = 1252 \cdot kips$ | $T_{uvmax_x} = -242 \cdot kip \cdot ft$ | $M_{uvmax_x} = 719\, ft \cdot kips$ | $N_{uvmax_x} = -55 \cdot kips$ |
| $V_{uvmin_x} = 307 \cdot kips$ | $T_{uvmin_x} = 4363 \cdot kip \cdot ft$ | $M_{uvmin_x} = 632\, ft \cdot kips$ | $N_{uvmin_x} = -47 \cdot kips$ |
| $V_{utmax_x} = 331 \cdot kips$ | $T_{utmax_x} = 4373 \cdot kip \cdot ft$ | $M_{utmax_x} = 634\, ft \cdot kips$ | $N_{utmax_x} = -47 \cdot kips$ |
| $V_{utmin_x} = 1227 \cdot kips$ | $T_{utmin_x} = -292 \cdot kip \cdot ft$ | $M_{utmin_x} = 703\, ft \cdot kips$ | $N_{utmin_x} = -55 \cdot kips$ |

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***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = 1.357 \times 10^{-8}\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad \left| \begin{array}{l} K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ K_{2_i} \leftarrow 2 \\ K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \end{array} \right. \\ K \end{array} \right.$$

$K_x = 1$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 2480 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 105.25 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 94.725 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \end{array} \right. \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = 0.0063$

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$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 51.054 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 0.838$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 84.164 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \ \text{ if } \ \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \ \text{ otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \ \text{ if } \ UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \ \text{ otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 385.125\,kip$

$V_{LLwebvmax_y} := \dfrac{1.35 V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \ \text{ if } \ UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \ \text{ otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 240.975 \cdot kips$

$$RF_{vpos} := \text{for } i \in y \;\; V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{vpos_{x,1}} = -0.22$$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$$\varepsilon_{svmin} := \text{for } i \in y \;\; \varepsilon_1 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \text{ if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \text{ otherwise}$$

$$\varepsilon$$

$$\varepsilon_{svmin_x} = 0.00174$$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 35.095 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 2.081$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 208.975 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \ \text{ if } \ \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \ \text{ otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"Yes"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if } UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$ $\qquad V_{dwebvmin_x} = 344.929\,kip$

$V_{LLwebvmin_y} := \dfrac{1.35 V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if } UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_y} = -329.434 \cdot kips$

$$RF_{vneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{vmin_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$RF_{vneg_{x,1}} = 2.667$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left|\left|V_{utmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \text{ if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \text{ otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{stmax_x} = 0.00186$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 35.508 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 2.005$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 201.251 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \text{ if } \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \text{ otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad UseTorsionMaxTorsion_x = \text{"Yes"}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y}\left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \text{ if } UseTorsionMaxTorsion_y = \text{"} \\ (0 \cdot kips) \text{ otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 344.929\, kip$

$V_{LLwebtmax_y} := \dfrac{1.35 V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y}\left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \text{ if } UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \text{ otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = -317.626 \cdot kips$

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$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tpos_{x,1}} = 2.667}$$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{stmin_x} = 0.00617$$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 50.59 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 0.853$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 85.653 \cdot kips$

$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \ \text{ if } \ \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \ \text{ otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinTorsion_x = \text{"No"}}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$V_{dwebtmin_y} := \dfrac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \ \text{ if } \ UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \ \text{ otherwise} \end{array} \right.$

$V_{dwebtmin_x} = 385.125\,kip$

$V_{LLwebtmin_y} := \dfrac{1.35 V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y} \left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \ \text{ if } \ UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \ \text{ otherwise} \end{array} \right.$

$V_{LLwebtmin_x} = 228.15 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = -0.208}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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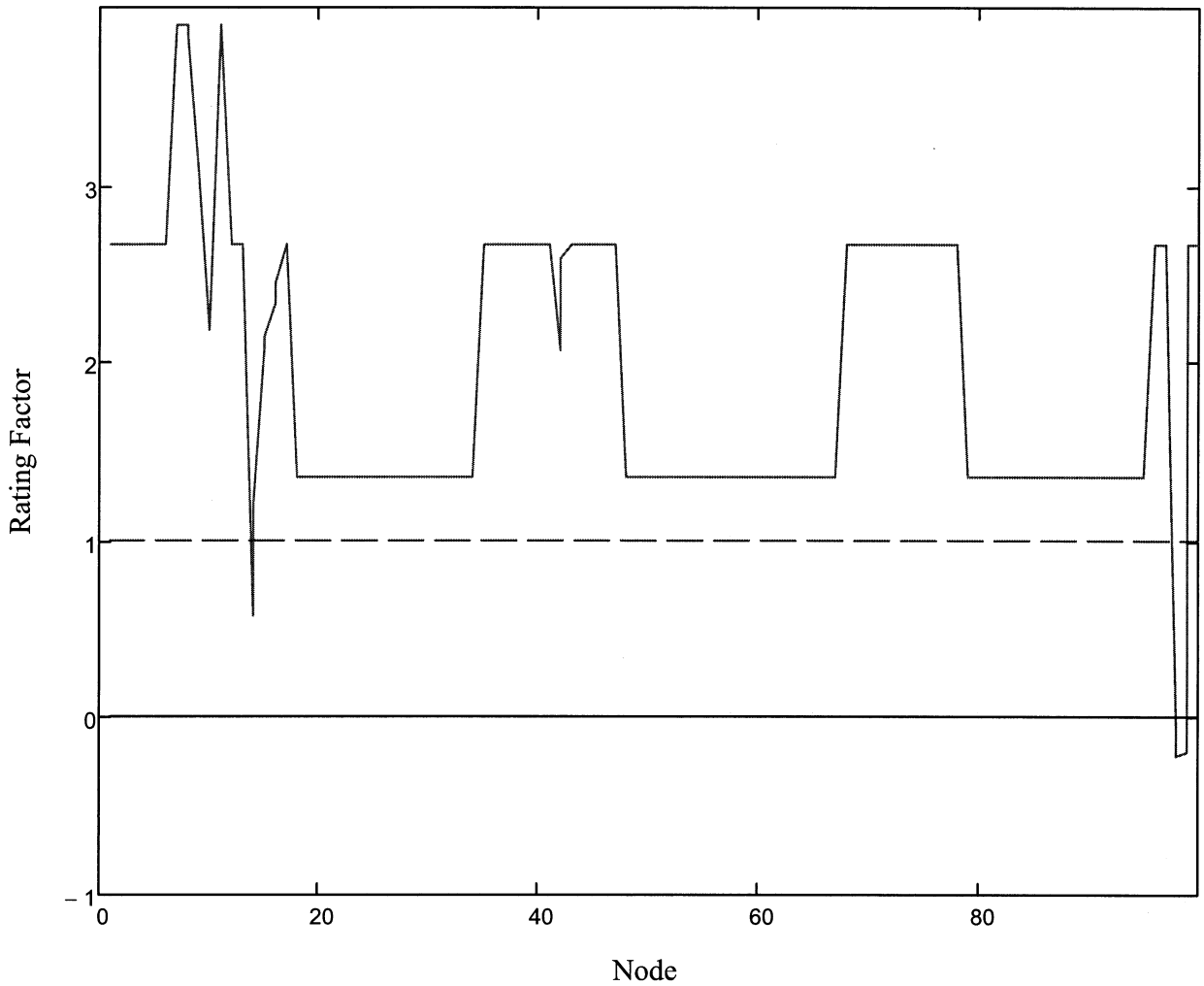
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— - Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = -0.22$ at node $minRF_2 = 98$ $minRF_4$ = "Ahead"

Minimum Rating Factor for Transverse Bending is $minRF_3 = 1.358$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 107.094 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{rd_x} = 23.483 \cdot kip \cdot in$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.19 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.041 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 13.592 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.754 \cdot kip \cdot ft$

$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 142.4 \cdot kips$

$\phi V_{n2_y} := \phi \cdot (V_{cvmax_y} + V_{s2_y} + |V_{p_y}|)$ $\qquad \phi V_{n2_x} = 203.908 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 501.474 \cdot kips$

$\phi V_{n_3} := \phi \cdot (V_{cvmax_x} + V_{s3_x} + |V_{p_x}|)$ $\qquad \phi V_{n_3} = 527.075 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 1.541 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.754 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_{n_i} \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow |V_d| \\ V_{u_{i+1}} \leftarrow |V_d + V_{LL}| \end{array} \right. \\ V_u \end{array} \right.$$

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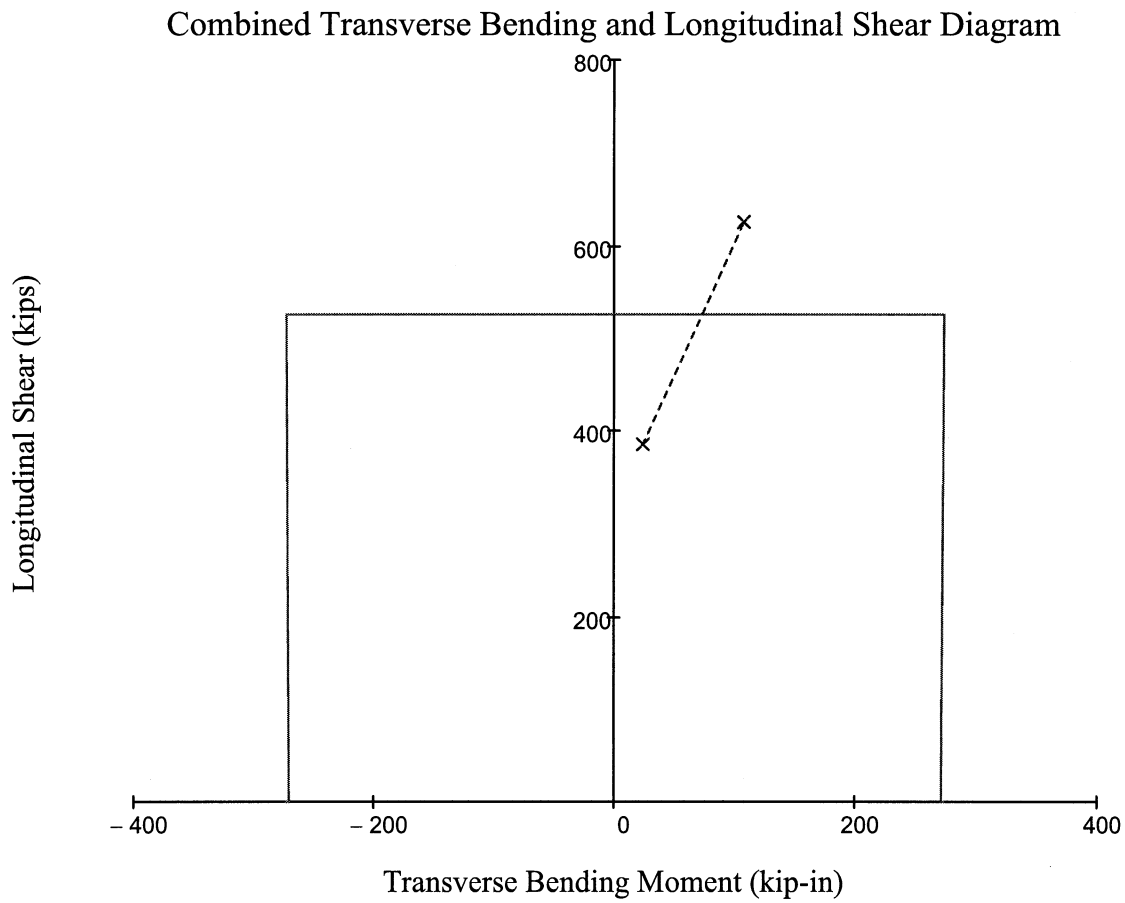



The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.985$

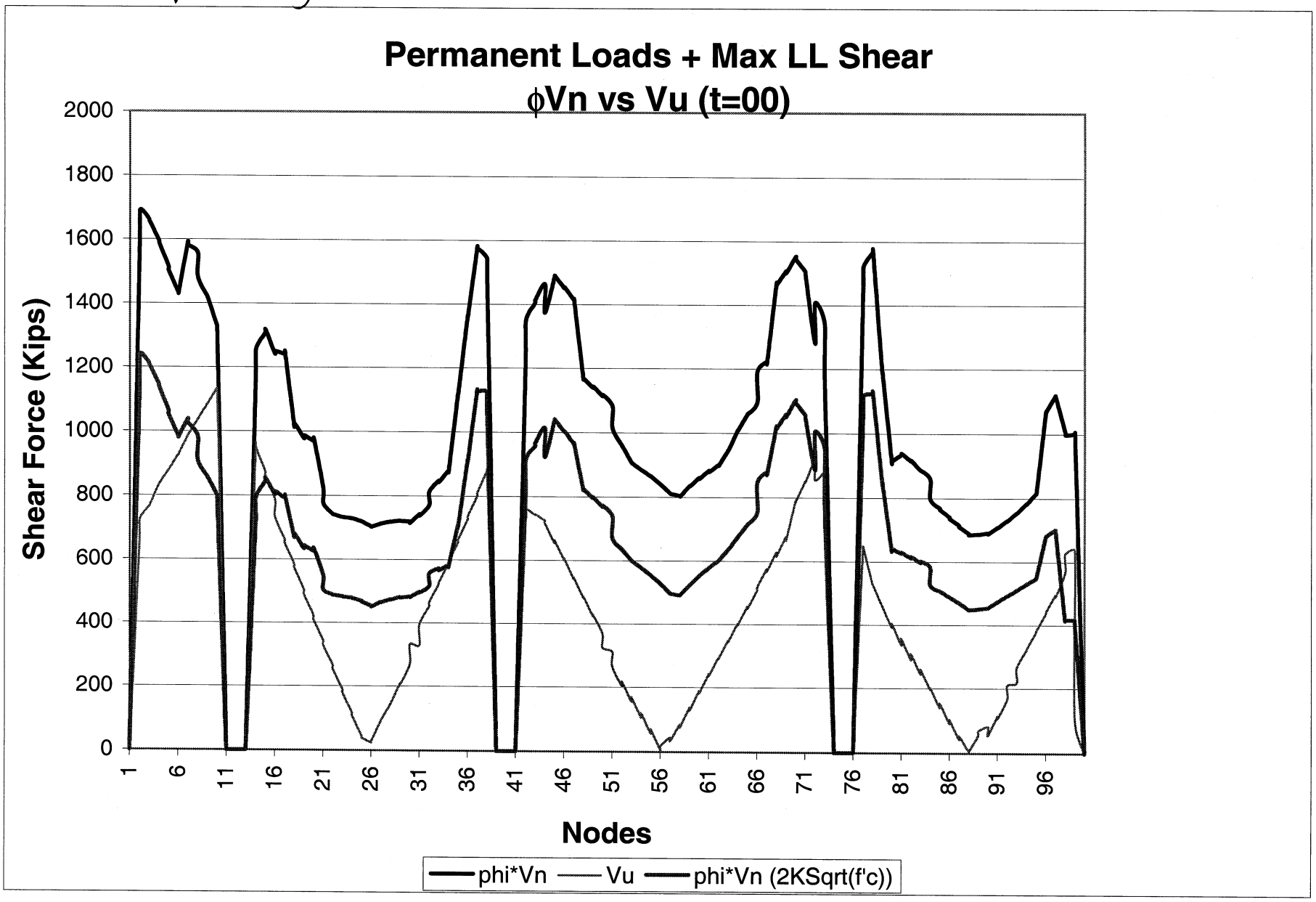
$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 0.553$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 0.573$

Ramp D seg 6 - Excel

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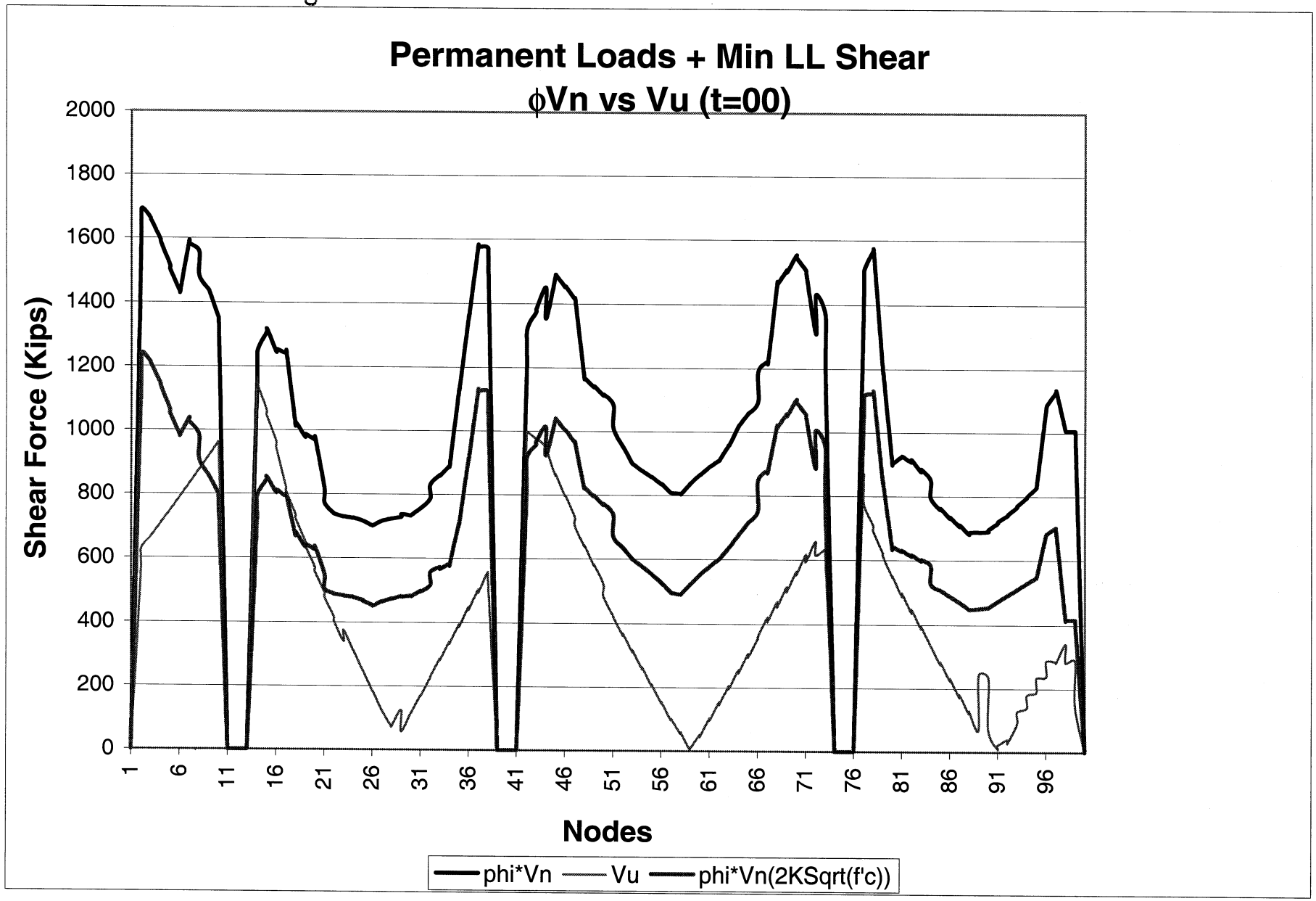
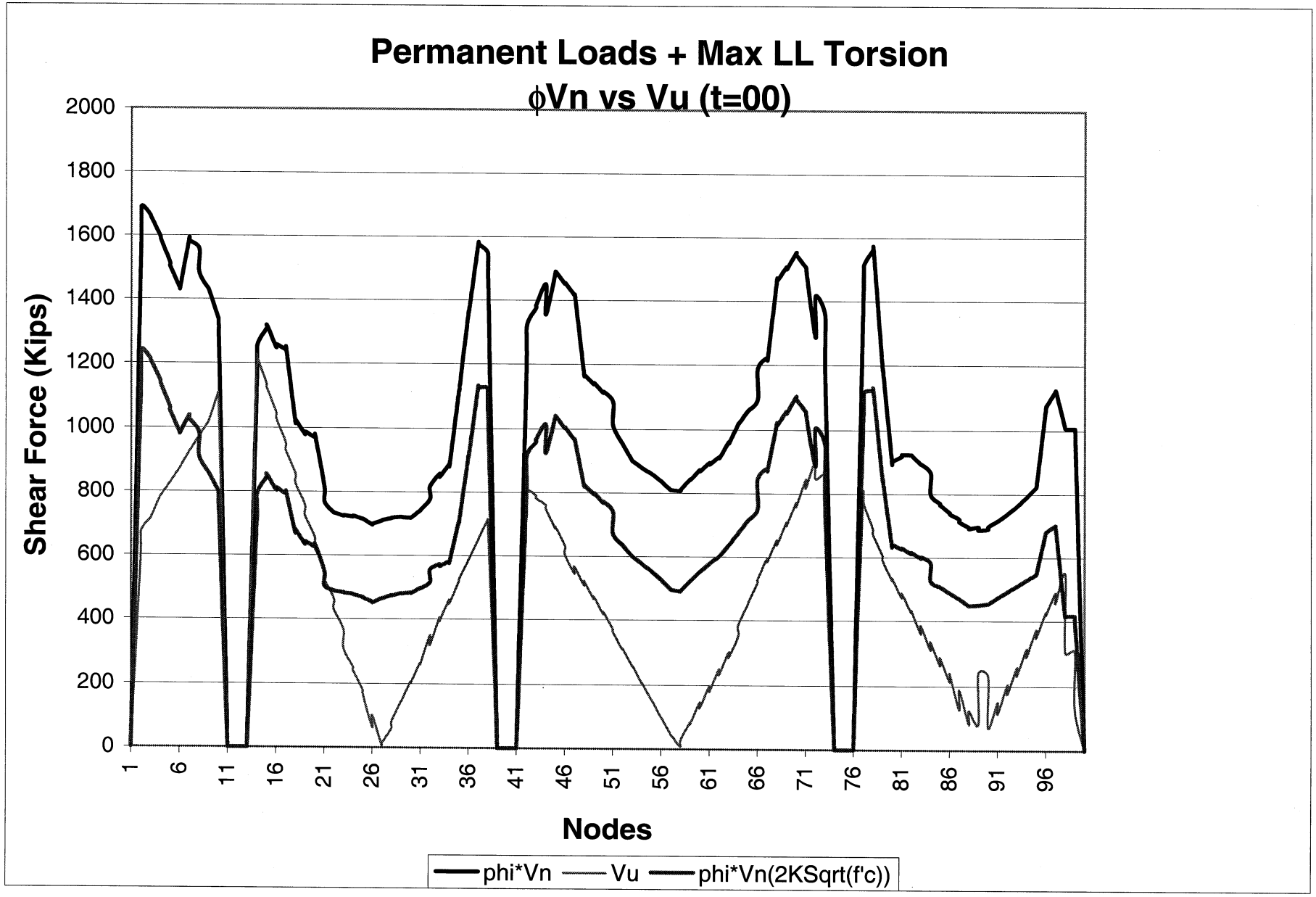
Ramp D Seg 6


Permanent Loads + Min LL Shear
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

Ramp D Seg. 6

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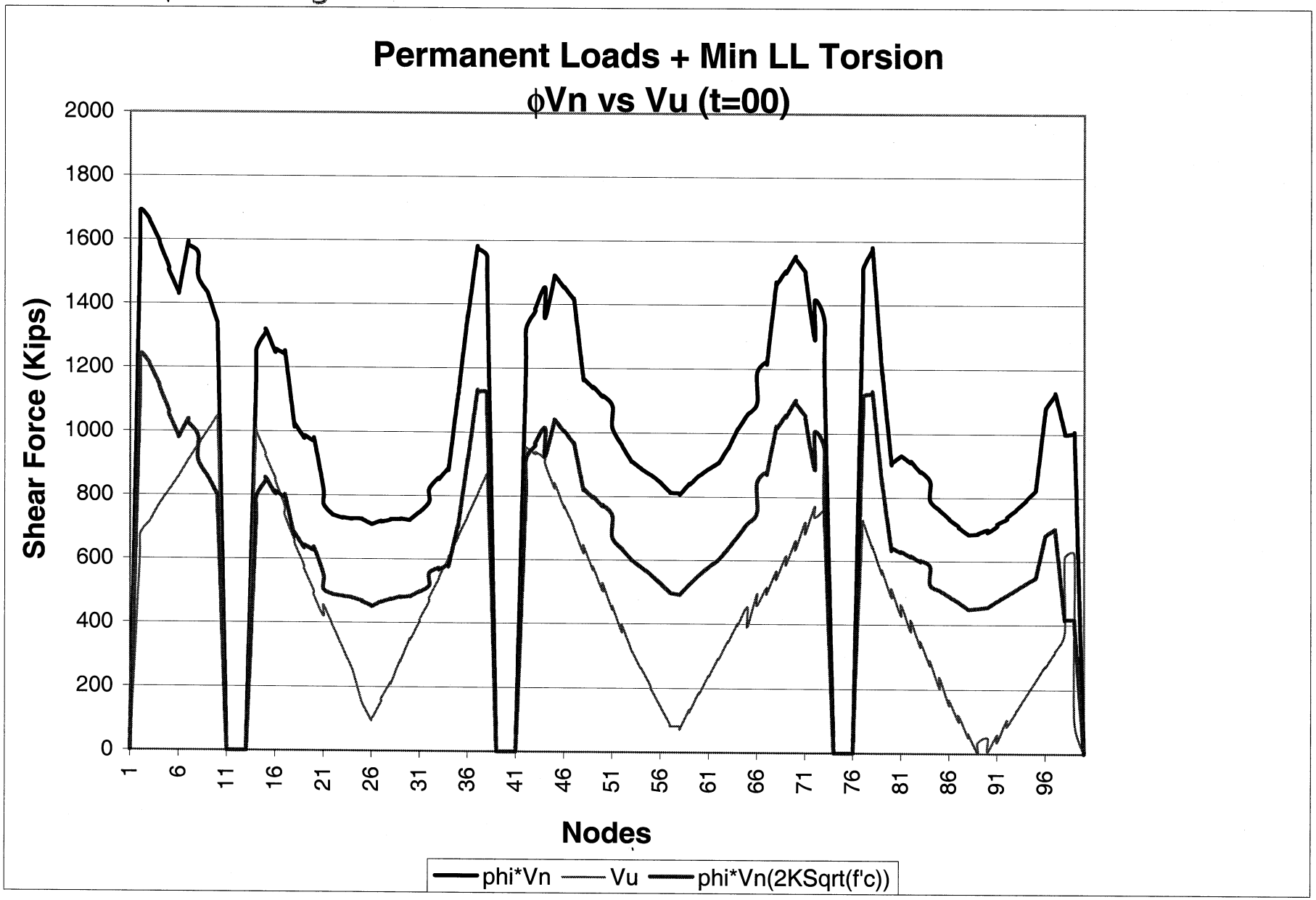
Ramp D Seg 6


Permanent Loads + Min LL Torsion
ϕVn vs Vu (t=00)
Shear Force (Kips)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
6
11
16
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56
61
66
71
76
81
86
91
96
Nodes
phi*Vn
Vu
phi*Vn(2KSqrt(f'c))

# 8.6 Comparison of the MCFT Shear Analysis—Tabularized Values (2007) Vs. Equations (2009)

## 8.6 Comparison of the MCFT Shear Analysis - Tabularized Values (2007) Vs. Equations (2009)

**URS**

Page ____ of ____

Job ____ Project No. ____ Sheet ____ of ____

Description ____ Computed by RJB Date 9/25/09

Checked by ____ Date ____

Reference

Node 121 Back

$$v = \frac{V_n - V_p}{b_w(\gamma d)}$$

$$v = \frac{2168 - 1175}{(15'')(95.4'')} = \underline{0.694 \text{ ksi}} \qquad v/f'_c = \frac{0.694}{5} = \underline{0.139}$$

$$\varepsilon_x = \frac{\left(\frac{M_u}{d_v} + 0.5 N_u + 0.5 |V_u - V_p| \cot\theta - A_{ps} f_{po}\right)}{2\left(E_s A_s + E_p A_{ps}\right)}$$

Assume $\theta = 37°$

$$\varepsilon_x = \frac{\overset{54.97}{\frac{437 \times 12}{95.4}} + \overset{22.5}{0.5(47)} + \overset{974.4}{0.5(2168 - 1175)\cot 37°} - 0}{2\left(\underbrace{(29000)(9.2 \text{ in}^2)}_{266800.}\right)}$$

$\varepsilon_x = \underline{0.00138}$ → value not listed in table

$\beta = 2.08$ (for $v_u/f'_c = 0.150$) ?

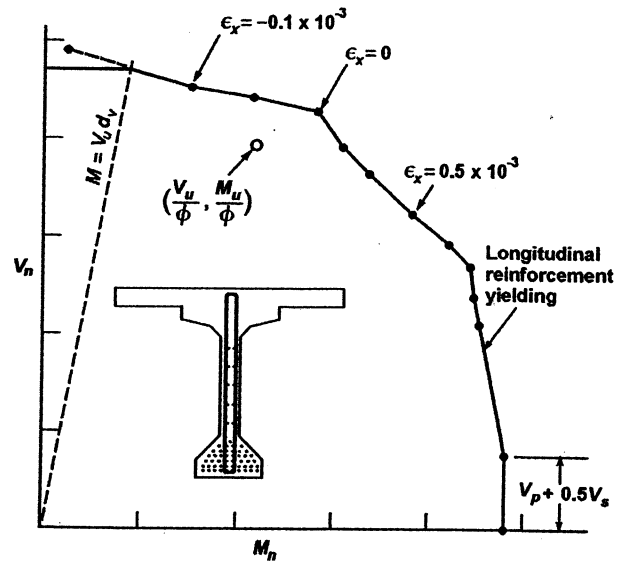


**Figure C5.8.3.4.2-6 Typical Shear-Moment Interaction Diagram.**

More details on the procedures used in deriving the tabulated values of θ and β are given in Collins and Mitchell (*1991*).

**Table 5.8.3.4.2-1 Values of θ and β for Sections with Transverse Reinforcement.**

| $\frac{v_u}{f'_c}$ | $\varepsilon_x \times 1{,}000$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ≤−0.20 | ≤−0.10 | ≤−0.05 | ≤0 | ≤0.125 | ≤0.25 | ≤0.50 | ≤0.75 | ≤1.00 |
| ≤0.075 | 22.3<br>6.32 | 20.4<br>4.75 | 21.0<br>4.10 | 21.8<br>3.75 | 24.3<br>3.24 | 26.6<br>2.94 | 30.5<br>2.59 | 33.7<br>2.38 | 36.4<br>2.23 |
| ≤0.100 | 18.1<br>3.79 | 20.4<br>3.38 | 21.4<br>3.24 | 22.5<br>3.14 | 24.9<br>2.91 | 27.1<br>2.75 | 30.8<br>2.50 | 34.0<br>2.32 | 36.7<br>2.18 |
| ≤0.125 | 19.9<br>3.18 | 21.9<br>2.99 | 22.8<br>2.94 | 23.7<br>2.87 | 25.9<br>2.74 | 27.9<br>2.62 | 31.4<br>2.42 | 34.4<br>2.26 | 37.0<br>2.13 |
| ≤0.150 | 21.6<br>2.88 | 23.3<br>2.79 | 24.2<br>2.78 | 25.0<br>2.72 | 26.9<br>2.60 | 28.8<br>2.52 | 32.1<br>2.36 | 34.9<br>2.21 | 37.3<br>2.08 |
| ≤0.175 | 23.2<br>2.73 | 24.7<br>2.66 | 25.5<br>2.65 | 26.2<br>2.60 | 28.0<br>2.52 | 29.7<br>2.44 | 32.7<br>2.28 | 35.2<br>2.14 | 36.8<br>1.96 |
| ≤0.200 | 24.7<br>2.63 | 26.1<br>2.59 | 26.7<br>2.52 | 27.4<br>2.51 | 29.0<br>2.43 | 30.6<br>2.37 | 32.8<br>2.14 | 34.5<br>1.94 | 36.1<br>1.79 |
| ≤0.225 | 26.1<br>2.53 | 27.3<br>2.45 | 27.9<br>2.42 | 28.5<br>2.40 | 30.0<br>2.34 | 30.8<br>2.14 | 32.3<br>1.86 | 34.0<br>1.73 | 35.7<br>1.64 |
| ≤0.250 | 27.5<br>2.39 | 28.6<br>2.39 | 29.1<br>2.33 | 29.7<br>2.33 | 30.6<br>2.12 | 31.3<br>1.93 | 32.8<br>1.70 | 34.3<br>1.58 | 35.8<br>1.50 |

# APPENDIX B5 GENERAL PROCEDURE FOR SHEAR DESIGN WITH TABLES

[*Appendix B5 is completely new in the 2008 interim. For ease of reading, underlining has been omitted.*]

## B5.1 BACKGROUND

The general procedure herein is an acceptable alternative to the procedure specified in Article 5.8.3.4.2. The procedure in this Appendix utilizes tabularized values of β and θ instead of Eqs. 5.8.3.4.2-1, 5.8.3.4.2-2, and 5.8.3.4.2-3. Appendix B5 is a complete presentation of the general procedures in LRFD Design (*2007*) without any interim changes.

## B5.2 SECTIONAL DESIGN MODEL—GENERAL PROCEDURE

For sections containing at least the minimum amount of transverse reinforcement specified in Article 5.8.2.5, the values of β and θ shall be as specified in Table 1. In using this table, $\varepsilon x$ shall be taken as the calculated longitudinal strain at the middepth of the member when the section is subjected to $M_u$, $N_u$, and $V_u$ as shown in Figure 1.

For sections containing less transverse reinforcement than specified in Article 5.8.2.5, the values of β and θ shall be as specified in Table 2. In using this table, $\varepsilon x$ shall be taken as the largest calculated longitudinal strain which occurs within the web of the member when the section is subjected to $N_u$, $M_u$, and $V_u$ as shown in Figure 2.

Unless more accurate calculations are made, $\varepsilon_x$ shall be determined as:

- If the section contains at least the minimum transverse reinforcement as specified in Article 5.8.2.5:

$$\varepsilon_x = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + 0.5|V_u - V_p|\cot\theta - A_{ps}f_{po}\right)}{2(E_sA_s + E_pA_{ps})} \qquad \text{(B5.2-1)}$$

The initial value of $\varepsilon_x$ should not be taken greater than 0.001.

## CB5.2

The shear resistance of a member may be determined by performing a detailed sectional analysis that satisfies the requirements of Article 5.8.3.1. Such an analysis (see Figure C1) would show that the shear stresses are not uniform over the depth of the web and that the direction of the principal compressive stresses changes over the depth of the beam. The more direct procedure given herein assumes that the concrete shear stresses are uniformly distributed over an area $b_v$ wide and $d_v$ deep, that the direction of principal compressive stresses (defined by angle θ) remains constant over $d_v$, and that the shear strength of the section can be determined by considering the biaxial stress conditions at just one location in the web. See Figure C2.

Members containing at least the minimum amount of transverse reinforcement have a considerable capacity to redistribute shear stresses from the most highly strained portion of the cross-section to the less highly strained portions. Because of this capacity to redistribute, it is appropriate to use the middepth of the member as the location at which the biaxial stress conditions are determined. Members that contain no transverse reinforcement, or contain less than the minimum amount of transverse reinforcement, have less capacity for shear stress redistribution. Hence, for such members, it is appropriate to perform the biaxial stress calculations at the location in the web subject to the highest longitudinal tensile strain; see Figure 2.

- If the section contains less than the minimum transverse reinforcement as specified in Article 5.8.2.5:

$$\varepsilon_x = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + 0.5|V_u - V_p|\cot\theta - A_{ps}f_{po}\right)}{E_sA_s + E_pA_{ps}} \tag{B5.2-2}$$

The initial value of $\varepsilon_x$ should not be taken greater than 0.002.

- If the value of $\varepsilon_x$ from Eqs. 1 or 2 is negative, the strain shall be taken as:

$$\varepsilon_x = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + 0.5|V_u - V_p|\cot\theta - A_{ps}f_{po}\right)}{2\left(E_cA_c + E_sA_s + E_pA_{ps}\right)} \tag{B5.2-3}$$

where:

$A_c$ = area of concrete on the flexural tension side of the member as shown in Figure 1 (in.$^2$)

$A_{ps}$ = area of prestressing steel on the flexural tension side of the member, as shown in Figure 1 (in.$^2$)

$A_s$ = area of nonprestressed steel on the flexural tension side of the member at the section under consideration, as shown in Figure 1. In calculating $A_s$ for use in this equation, bars which are terminated at a distance less than their development length from the section under consideration shall be ignored (in.$^2$)

$f_{po}$ = a parameter taken as modulus of elasticity of prestressing tendons multiplied by the locked-in difference in strain between the prestressing tendons and the surrounding concrete. For the usual levels of prestressing, a value of $0.7f_{pu}$ will be appropriate for both pretensioned and post-tensioned members (ksi)

$M_u$ = factored moment, not to be taken less than $V_ud_v$ (kip-in.)

$N_u$ = factored axial force, taken as positive if tensile and negative if compressive (kip)

$V_u$ = factored shear force (kip)

The longitudinal strain, $\varepsilon_x$, can be determined by the procedure illustrated in Figure C3. The actual section is represented by an idealized section consisting of a flexural tension flange, a flexural compression flange, and a web. The area of the compression flange is taken as the area on the flexure compression side of the member, i.e., the total area minus the area of the tension flange as defined by $A_c$. After diagonal cracks have formed in the web, the shear force applied to the web concrete, $V_u - V_p$, will primarily be carried by diagonal compressive stresses in the web concrete. These diagonal compressive stresses will result in a longitudinal compressive force in the web concrete of $(V_u - V_p)\cot\theta$. Equilibrium requires that this longitudinal compressive force in the web needs to be balanced by tensile forces in the two flanges, with half the force, that is $0.5(V_u - V_p)\cot\theta$, being taken by each flange. To avoid a trial and error iteration process, it is a convenient simplification to take this flange force due to shear as $V_u - V_p$. This amounts to taking $0.5\cot\theta = 1.0$ in the numerator of Eqs. 1, 2, and 3. This simplification is not expected to cause a significant loss of accuracy. After the required axial forces in the two flanges are calculated, the resulting axial strains, $\varepsilon_t$ and $\varepsilon_c$, can be calculated based on the axial force-axial strain relationship shown in Figure C4.

For members containing at least the minimum amount of transverse reinforcement, $\varepsilon_x$ can be taken as:

$$\varepsilon_x = \frac{\varepsilon_t + \varepsilon_c}{2} \tag{CB5.2-1}$$

where $\varepsilon_t$ and $\varepsilon_c$ are positive for tensile strains and negative for compressive strains. If, for a member subject to flexure, the strain $\varepsilon_c$ is assumed to be negligibly small, then $\varepsilon_x$ becomes one half of $\varepsilon_t$. This is the basis for the expression for $\varepsilon_x$ given in Eq. 1. For members containing less than the minimum amount of transverse reinforcement, Eq. 2 makes the conservative simplification that $\varepsilon_x$ is equal to $\varepsilon_t$.

In some situations, it will be more appropriate to determine $\varepsilon_x$ using the more accurate procedure of Eq. C1 rather than the simpler Eqs. 1 through 3. For example, the shear capacity of sections near the ends of precast, pretensioned simple beams made continuous for live load will be estimated in a very conservative manner by Eqs. 1 through 3 because, at these locations, the prestressing strands are located on the flexural compression side and, therefore, will not be included in $A_{ps}$. This will result in the benefits of prestressing not being accounted for by Eqs. 1 through 3.

Within the transfer length, $f_{po}$ shall be increased linearly from zero at the location where the bond between the strands and concrete commences to its full value at the end of the transfer length.

The flexural tension side of the member shall be taken as the half-depth containing the flexural tension zone, as illustrated in Figure 1.

The crack spacing parameter $s_{xe}$, used in Table 2, shall be determined as:

$$s_{xe} = s_x \frac{1.38}{a_g + 0.63} \leq 80 \text{ in.} \qquad \text{(B5.2-4)}$$

where:

$a_g$ = maximum aggregate size (in.)

$s_x$ = the lesser of either $d_v$ or the maximum distance between layers of longitudinal crack control reinforcement, where the area of the reinforcement in each layer is not less than $0.003 b_v s_x$, as shown in Figure 3 (in.)

In the evaluation of $\varepsilon_x$, $\beta$ and $\theta$, the following should be considered:

- $M_u$ shall be taken as positive quantities and $M_u$ shall not be taken less than $(V_u - V_p)d_v$.
- In calculating $A_s$ and $A_{ps}$ the area of bars or tendons which are terminated less than their development length from the section under consideration shall be reduced in proportion to their lack of full development.
- The value of $\varepsilon_x$ calculated from Eqs. 2 and 3 should not be taken as less than $-0.20 \times 10^{-3}$.
- For sections closer than $d_v$ to the face of the support, the value of $\varepsilon_x$ calculated at $d_v$ from the face of the support may be used in evaluating $\beta$ and $\theta$.
- If the axial tension is large enough to crack the flexural compression face of the section, the resulting increase in $\varepsilon_x$ shall be taken into account. In lieu of more accurate calculations, the value calculated from Eq. 2 should be doubled.
- It is permissible to determine $\beta$ and $\theta$ from Tables 1 and 2 using a value of $\varepsilon_x$ that is greater that that calculated from Eqs. 2 and 3; however, $\varepsilon_x$ shall not be taken greater than $3.0 \times 10^{-3}$.

Absolute value signs were added to Eqs. 1 through 3 in 2004. This notation replaced direction in the nomenclature to take $M_u$ and $V_u$ as positive values. For shear, absolute value signs in Eqs. 1 through 3 are needed to properly consider the effects due to $V_u$ and $V_p$ in sections containing a parabolic tendon path which may not change signs at the same location as shear demand, particularly at midspan.

For pretensioned members, $f_{po}$ can be taken as the stress in the strands when the concrete is cast around them, i.e., approximately equal to the jacking stress. For post-tensioned members, $f_{po}$ can be conservatively taken as the average stress in the tendons when the posttensioning is completed.

Note that in both Table 1 and Table 2, the values of $\beta$ and $\theta$ given in a particular cell of the table can be applied over a range of values. Thus from Table 1, $\theta = 34.4°$ and $\beta = 2.26$ can be used provided that $\varepsilon_x$ is not greater than $0.75 \times 10^{-3}$ and $v_u/f'_c$ is not greater than 0.125. Linear interpolation between the values given in the tables may be used, but is not recommended for hand calculations. Assuming a value of $\varepsilon_x$ larger than the value calculated using Eqs. 1, 2, or 3, as appropriate, is permissible and will result in a higher value of $\theta$ and a lower value of $\beta$. Higher values of $\theta$ will typically require more transverse shear reinforcement, but will decrease the tension force required to be resisted by the longitudinal reinforcement. Figure C5 illustrates the shear design process by means of a flow chart. This figure is based on the simplified assumption that $0.5 \cot \theta = 1.0$.

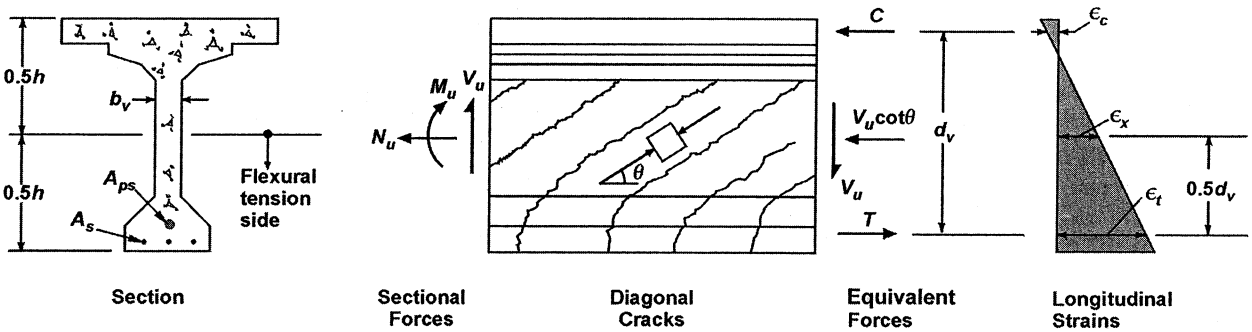


**Figure B5.2-1 Illustration of Shear Parameters for Section Containing at Least the Minimum Amount of Transverse Reinforcement, $V_p = 0$.**

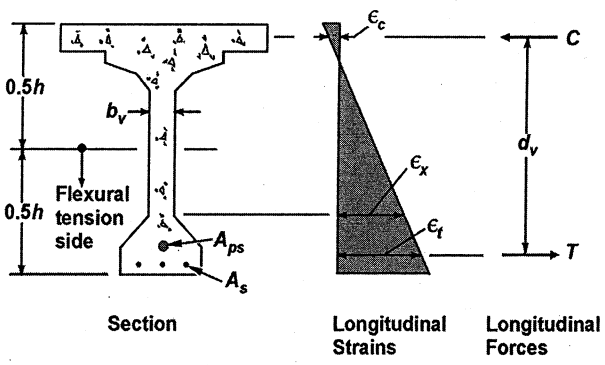


**Figure B5.2-2 Longitudinal Strain, $\varepsilon_x$, for Sections Containing Less than the Minimum Amount of Transverse Reinforcement.**

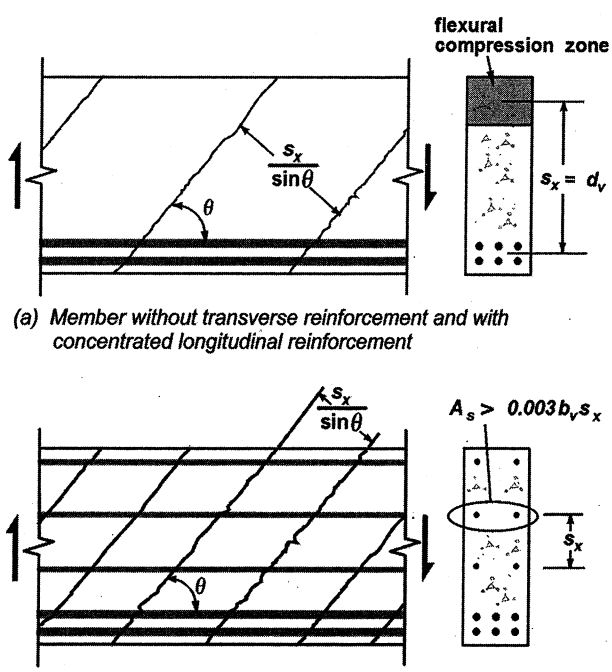


**Figure B5.2-3 Definition of Crack Spacing Parameter, $s_x$.**

For sections containing a specified amount of transverse reinforcement, a shear-moment interaction diagram, see Figure C6, can be calculated directly from the procedures in this Article. For a known concrete strength and a certain value of $\varepsilon x$, each cell of Table 1 corresponds to a certain value of $v_u/f'_c$, i.e., a certain value of $V_n$. This value of $Vn$ requires an amount of transverse reinforcement expressed in terms of the parameter $A_v f_y/(b_v s)$. The shear capacity corresponding to the provided shear reinforcement can be found by linearly interpolating between the values of $V_n$ corresponding to two consecutive cells where one cell requires more transverse reinforcement than actually provided and the other cell requires less reinforcement than actually provided. After $V_n$ and θ have been found in this manner, the corresponding moment capacity $M_n$ can be found by calculating, from Eqs. 1 through 3, the moment required to cause this chosen value of $\varepsilon x$, and calculating, from Eq. 5.8.3.5-1, the moment required to yield the reinforcement. The predicted moment capacity will be the lower of these two values. In using Eqs. 5.8.2.9-1, 5.8.3.5-1, and Eqs. 1 through 3 of the procedure to calculate a $V_n - M_n$ interaction diagram, it is appropriate to replace $V_u$ by $V_n$, $M_u$ by $M_n$, and $N_u$ by $N_n$ and to take the value of φ as 1.0. With an appropriate spreadsheet, the use of shear-moment interaction diagrams is a convenient way of performing shear design and evaluation.

The values of β and θ listed in Table 1 and Table 2 are based on calculating the stresses that can be transmitted across diagonally cracked concrete. As the cracks become wider, the stress that can be transmitted decreases. For members containing at least the minimum amount of transverse reinforcement, it is assumed that the diagonal cracks will be spaced about 12.0 in. apart. For members without transverse reinforcement, the spacing of diagonal cracks inclined at θ° to the longitudinal reinforcement is assumed to be $s_x/\sin\theta$, as shown in Figure 3. Hence, deeper members having larger values of $sx$ are calculated to have more widely spaced cracks and hence, cannot transmit such high shear stresses. The ability of the crack surfaces to transmit shear stresses is influenced by the aggregate size of the concrete.

Members made from concretes that have a smaller maximum aggregate size will have a larger value of $s_{xe}$ and hence, if there is no transverse reinforcement, will have a smaller shear strength.

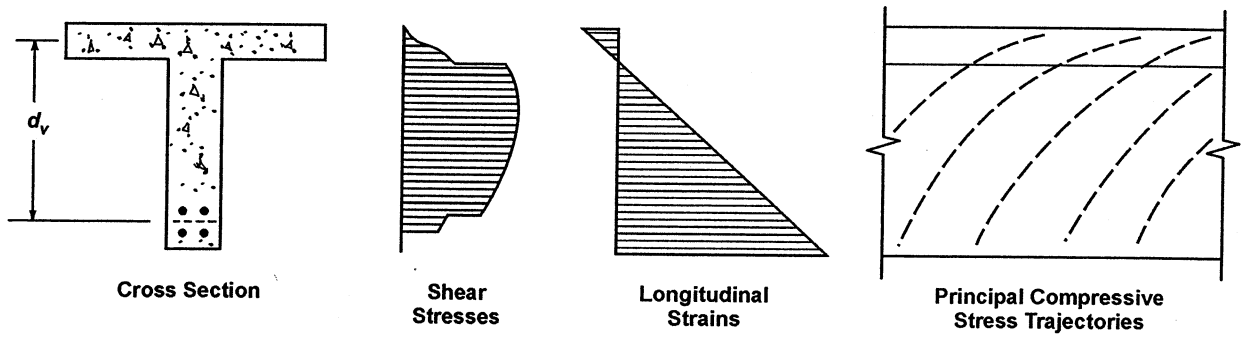


**Figure CB5.2-1 Detailed Sectional Analysis to Determine Shear Resistance in Accordance with Article 5.8.3.1.**

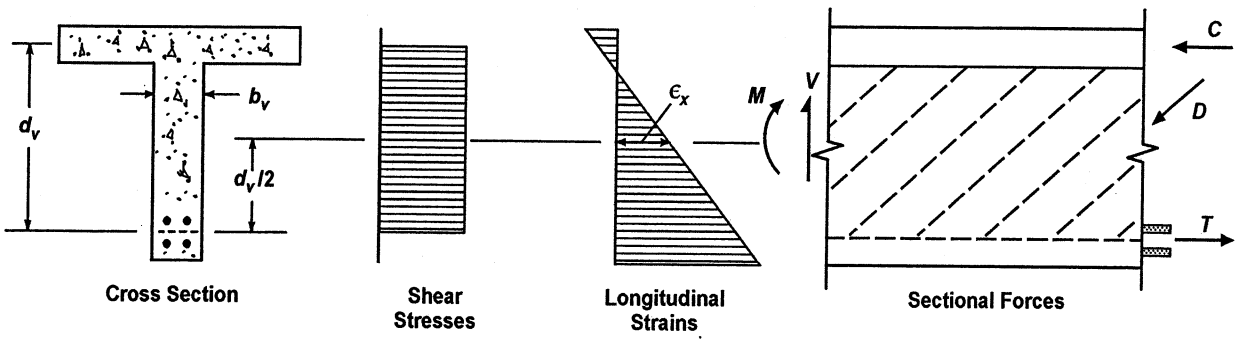


**Figure CB5.2-2 More Direct Procedure to Determine Shear Resistance in Accordance with Article 5.8.3.4.2.**

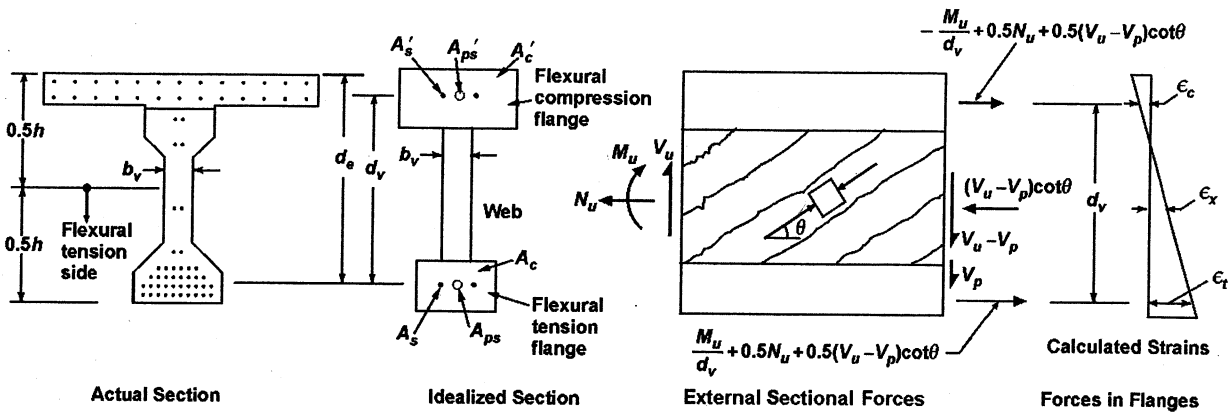


**Figure CB5.2-3 More Accurate Calculation Procedure for Determining $\varepsilon_x$.**

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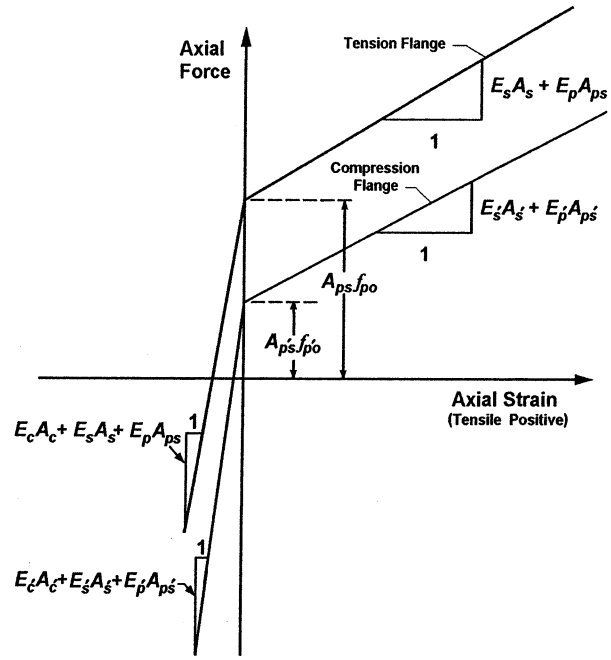


**Figure CB5.2-4 Assumed Relations Between Axial Force in Flange and Axial Strain of Flange.**

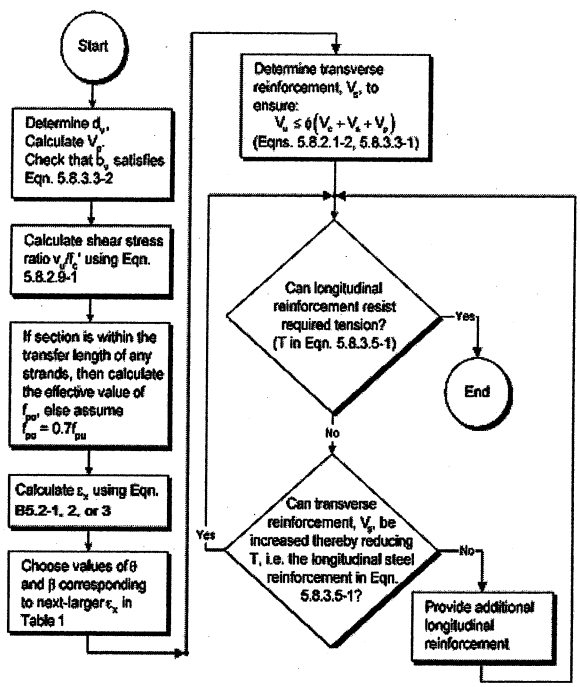


**Figure CB5.2-5 Flow Chart for Shear Design of Section Containing at Least Minimum Transverse Reinforcement.**

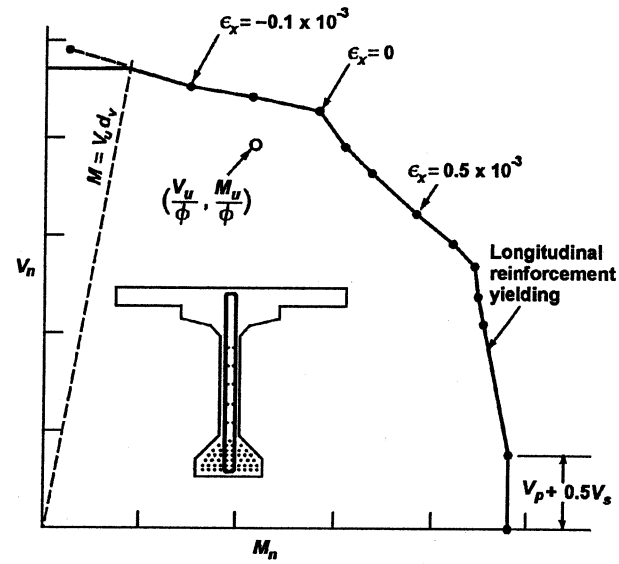


**Figure CB5.2-6 Typical Shear-Moment Interaction Diagram.**

More details on the procedures used in deriving the tabulated values of θ and β are given in Collins and Mitchell (*1991*).

**Table B5.2-1 Values of θ and β for Sections with Transverse Reinforcement.**

| $\frac{v_u}{f'_c}$ | $\varepsilon_x \times 1{,}000$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ≤–0.20 | ≤–0.10 | ≤–0.05 | ≤0 | ≤0.125 | ≤0.25 | ≤0.50 | ≤0.75 | ≤1.00 |
| ≤0.075 | 22.3<br>6.32 | 20.4<br>4.75 | 21.0<br>4.10 | 21.8<br>3.75 | 24.3<br>3.24 | 26.6<br>2.94 | 30.5<br>2.59 | 33.7<br>2.38 | 36.4<br>2.23 |
| ≤0.100 | 18.1<br>3.79 | 20.4<br>3.38 | 21.4<br>3.24 | 22.5<br>3.14 | 24.9<br>2.91 | 27.1<br>2.75 | 30.8<br>2.50 | 34.0<br>2.32 | 36.7<br>2.18 |
| ≤0.125 | 19.9<br>3.18 | 21.9<br>2.99 | 22.8<br>2.94 | 23.7<br>2.87 | 25.9<br>2.74 | 27.9<br>2.62 | 31.4<br>2.42 | 34.4<br>2.26 | 37.0<br>2.13 |
| ≤0.150 | 21.6<br>2.88 | 23.3<br>2.79 | 24.2<br>2.78 | 25.0<br>2.72 | 26.9<br>2.60 | 28.8<br>2.52 | 32.1<br>2.36 | 34.9<br>2.21 | 37.3<br>2.08 |
| ≤0.175 | 23.2<br>2.73 | 24.7<br>2.66 | 25.5<br>2.65 | 26.2<br>2.60 | 28.0<br>2.52 | 29.7<br>2.44 | 32.7<br>2.28 | 35.2<br>2.14 | 36.8<br>1.96 |
| ≤0.200 | 24.7<br>2.63 | 26.1<br>2.59 | 26.7<br>2.52 | 27.4<br>2.51 | 29.0<br>2.43 | 30.6<br>2.37 | 32.8<br>2.14 | 34.5<br>1.94 | 36.1<br>1.79 |
| ≤0.225 | 26.1<br>2.53 | 27.3<br>2.45 | 27.9<br>2.42 | 28.5<br>2.40 | 30.0<br>2.34 | 30.8<br>2.14 | 32.3<br>1.86 | 34.0<br>1.73 | 35.7<br>1.64 |
| ≤0.250 | 27.5<br>2.39 | 28.6<br>2.39 | 29.1<br>2.33 | 29.7<br>2.33 | 30.6<br>2.12 | 31.3<br>1.93 | 32.8<br>1.70 | 34.3<br>1.58 | 35.8<br>1.50 |

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**Table B5.2-2 Values of θ and β for Sections with Less than Minimum Transverse Reinforcement.**

| $s_{xe}$, in. | $\varepsilon_x \times 1000$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤–0.20 | ≤–0.10 | ≤–0.05 | ≤0 | ≤0.125 | ≤0.25 | ≤0.50 | ≤0.75 | ≤1.00 | ≤1.50 | ≤2.00 |
| ≤5 | 25.4<br>6.36 | 25.5<br>6.06 | 25.9<br>5.56 | 26.4<br>5.15 | 27.7<br>4.41 | 28.9<br>3.91 | 30.9<br>3.26 | 32.4<br>2.86 | 33.7<br>2.58 | 35.6<br>2.21 | 37.2<br>1.96 |
| ≤10 | 27.6<br>5.78 | 27.6<br>5.78 | 28.3<br>5.38 | 29.3<br>4.89 | 31.6<br>4.05 | 33.5<br>3.52 | 36.3<br>2.88 | 38.4<br>2.50 | 40.1<br>2.23 | 42.7<br>1.88 | 44.7<br>1.65 |
| ≤15 | 29.5<br>5.34 | 29.5<br>5.34 | 29.7<br>5.27 | 31.1<br>4.73 | 34.1<br>3.82 | 36.5<br>3.28 | 39.9<br>2.64 | 42.4<br>2.26 | 44.4<br>2.01 | 47.4<br>1.68 | 49.7<br>1.46 |
| ≤20 | 31.2<br>4.99 | 31.2<br>4.99 | 31.2<br>4.99 | 32.3<br>4.61 | 36.0<br>3.65 | 38.8<br>3.09 | 42.7<br>2.46 | 45.5<br>2.09 | 47.6<br>1.85 | 50.9<br>1.52 | 53.4<br>1.31 |
| ≤30 | 34.1<br>4.46 | 34.1<br>4.46 | 34.1<br>4.46 | 34.2<br>4.43 | 38.9<br>3.39 | 42.3<br>2.82 | 46.9<br>2.19 | 50.1<br>1.84 | 52.6<br>1.60 | 56.3<br>1.30 | 59.0<br>1.10 |
| ≤40 | 36.6<br>4.06 | 36.6<br>4.06 | 36.6<br>4.06 | 36.6<br>4.06 | 41.2<br>3.20 | 45.0<br>2.62 | 50.2<br>2.00 | 53.7<br>1.66 | 56.3<br>1.43 | 60.2<br>1.14 | 63.0<br>0.95 |
| ≤60 | 40.8<br>3.50 | 40.8<br>3.50 | 40.8<br>3.50 | 40.8<br>3.50 | 44.5<br>2.92 | 49.2<br>2.32 | 55.1<br>1.72 | 58.9<br>1.40 | 61.8<br>1.18 | 65.8<br>0.92 | 68.6<br>0.75 |
| ≤80 | 44.3<br>3.10 | 44.3<br>3.10 | 44.3<br>3.10 | 44.3<br>3.10 | 47.1<br>2.71 | 52.3<br>2.11 | 58.7<br>1.52 | 62.8<br>1.21 | 65.7<br>1.01 | 69.7<br>0.76 | 72.4<br>0.62 |

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*5.8.3.4.1 Simplified Procedure for Nonprestressed Sections*

For concrete footings in which the distance from point of zero shear to the face of the column, pier or wall is less than $3d_v$ with or without transverse reinforcement, and for other nonprestressed concrete sections not subjected to axial tension and containing at least the minimum amount of transverse reinforcement specified in Article 5.8.2.5, or having an overall depth of less than 16.0 in., the following values may be used:

$$\beta = 2.0$$
$$\theta = 45°$$

*C5.8.3.4.1*

With β taken as 2.0 and θ as 45°, the expressions for shear strength become essentially identical to those traditionally used for evaluating shear resistance. Recent large-scale experiments (*Shioya et al. 1989*), however, have demonstrated that these traditional expressions can be seriously unconservative for large members not containing transverse reinforcement.

*5.8.3.4.2 General Procedure*

The parameters β and θ may be determined either by the provisions herein, or alternatively by the provisions of Appendix B5.

For sections containing at least the minimum amount of transverse reinforcement specified in Article 5.8.2.5, the value of β may be determined by Eq. 1:

$$\beta = \frac{4.8}{(1+750\varepsilon_s)} \qquad (5.8.3.4.2\text{-}1)$$

When sections do not contain at least the minimum amount of shear reinforcement, the value of β may be as specified in Eq. 2:

$$\beta = \frac{4.8}{(1+750\varepsilon_s)}\frac{51}{(39+s_{xe})} \qquad (5.8.3.4.2\text{-}2)$$

The value of θ in both cases may be as specified in Eq. 3:

$$\theta = 29+3500\varepsilon_s \qquad (5.8.3.4.2\text{-}3)$$

In Eqs. 1-3, $\varepsilon_s$ is the strain in nonprestressed longitudinal tension reinforcement as shown in Figures 1 and 2. In lieu of more involved procedures, $\varepsilon_s$ may be determined by Eq. 4:

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps}f_{po}\right)}{E_sA_s + E_pA_{ps}} \qquad (5.8.3.4.2\text{-}4)$$

The crack spacing parameter, $s_{xe}$, shall be determined as:

$$s_{xe} = s_x\frac{1.38}{a_g+0.63} \qquad (5.8.3.4.2\text{-}5)$$

*C5.8.3.4.2*

The shear resistance of a member may be determined by performing a detailed sectional analysis that satisfies the requirements of Article 5.8.3.1. Such an analysis, see Figure C1, would show that the shear stresses are not uniform over the depth of the web and that the direction of the principal compressive stresses changes over the depth of the beam. The more direct procedure given herein assumes that the concrete shear stresses are uniformly distributed over an area $b_v$ wide and $d_v$ deep, that the direction of principal compressive stresses (defined by angle θ and shown as *D*) remains constant over $d_v$, and that the shear strength of the section can be determined by considering the biaxial stress conditions at just one location in the web. See Figure C2.

This design procedure (*Collins et al, 1994*) was derived from the Modified Compression Field Theory (*MCFT, Vecchio, and Collins, 1986*) which is a comprehensive behavioral model for the response of diagonally cracked concrete subject to in-plane shear and normal stresses. Prior to the 2008 interim revisions, the General Procedure for shear design was iterative and required the use of tables for the evaluation of β and θ. With the 2008 revisions, this design procedure was modified to be non-iterative and algebraic equations were introduced for the evaluation of β and θ. These equations are functionally equivalent to those used in the Canadian design code (A23.2-M04, 2004), were also derived from the MCFT (*Bentz et al. 2006*), and were evaluated as appropriate for use in the *AASHTO LRFD Bridge Design Specifications* (*Hawkins et al., 2006, 2007*).

The longitudinal strain, $\varepsilon_s$, can be determined by the procedure illustrated in Figure C3. The actual section is represented by an idealized section consisting of a flexural tension flange, a flexural compression flange, and a web. The area of the compression flange is taken as the area on the flexure compression side of the member, i.e., the total area minus the area of the tension flange as defined by $A_c$. After diagonal cracks have formed in the web, the shear force applied to the web concrete, $V_u - V_p$, will primarily be carried by diagonal compressive stresses in the web concrete.



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where:

$12.0\,in. \le s_{xe} \le 80.0\ in.$

where:

$A_c$ = area of concrete on the flexural tension side of the member as shown in Figure 1 (in.$^2$)

$A_{ps}$ = area of prestressing steel on the flexural tension side of the member, as shown in Figure 1 (in.$^2$)

$A_s$ = area of nonprestressed steel on the flexural tension side of the member at the section under consideration, as shown in Figure 1. In calculating $A_s$ for use in this equation, bars which are terminated at a distance less than their development length from the section under consideration shall be ignored (in.$^2$)

$a_g$ = maximum aggregate size (in.)

$f_{po}$ = a parameter taken as modulus of elasticity of prestressing tendons multiplied by the locked-in difference in strain between the prestressing tendons and the surrounding concrete (ksi). For the usual levels of prestressing, a value of 0.7 $f_{pu}$ will be appropriate for both pretensioned and post-tensioned members

$N_u$ = factored axial force, taken as positive if tensile and negative if compressive (kip)

$M_u$ = factored moment, not to be taken less than $(V_u - V_p)d_v$ (kip-in.)

$s_x$ = the lesser of either $d_v$ or the maximum distance between layers of longitudinal crack control reinforcement, where the area of the reinforcement in each layer is not less than $0.003b_v s_x$, as shown in Figure 3 (in.)

$V_u$ = factored shear force (kip)

Within the transfer length, $f_{po}$ shall be increased linearly from zero at the location where the bond between the strands and concrete commences to its full value at the end of the transfer length.

The flexural tension side of the member shall be taken as the half-depth containing the flexural tension zone, as illustrated in Figure 1.

In the use of Eqs. 1 through 5, the following should be considered:

- $M_u$ should not be taken less than $(V_u - V_p)d_v$.

These diagonal compressive stresses will result in a longitudinal compressive force in the web concrete of $(V_u - V_p)$ cot θ. Equilibrium requires that this longitudinal compressive force in the web needs to be balanced by tensile forces in the two flanges, with half the force, that is 0.5 $(V_u - V_p)$ cot θ, being taken by each flange. For simplicity, 0.5 cot θ may be taken as = 2.0 and the longitudinal demand due to shear in the longitudinal tension reinforcement becomes $V_u - V_p$ without significant loss of accuracy. After the required axial forces in the two flanges are calculated, the resulting axial strains, $\varepsilon_t$ and $\varepsilon_c$, can be calculated based on the axial force-axial strain relationship shown in Figure C4.

For pretensioned members, $f_{po}$ can be taken as the stress in the strands when the concrete is cast around them, i.e., approximately equal to the jacking stress. For post-tensioned members, $f_{po}$ can be conservatively taken as the average stress in the tendons when the post-tensioning is completed.

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- In calculating $A_s$ and $A_{ps}$ the area of bars or tendons terminated less than their development length from the section under consideration should be reduced in proportion to their lack of full development.

- If the value of $\varepsilon_s$ calculated from Eq. 4 is negative, it should be taken as zero or the value should be recalculated with the denominator of Eq. 4 replaced by $(E_sA_s + E_pA_{ps} + E_cA_{ct})$. However, $\varepsilon_s$ should not be taken as less than $-0.40 \times 10^{-3}$.

- For sections closer than $d_v$ to the face of the support, the value of $\varepsilon_s$ calculated at $d_v$ from the face of the support may be used in evaluating β and θ.

- If the axial tension is large enough to crack the flexural compression face of the section, the value calculated from Eq. 4 should be doubled.

- It is permissible to determine β and θ from Eqs. 1 through 3 using a value of $\varepsilon_s$ which is greater that that calculated from Eq. 4 However $\varepsilon_s$ should not be taken greater than $6.0 \times 10^{-3}$. 0.006

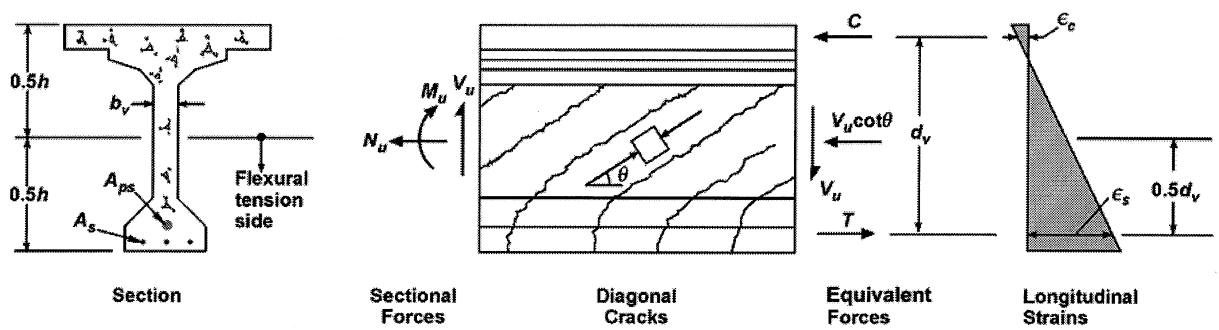


**Figure 5.8.3.4.2-1 Illustration of Shear Parameters for Section Containing at Least the Minimum Amount of Transverse Reinforcement, $V_p = 0$.**

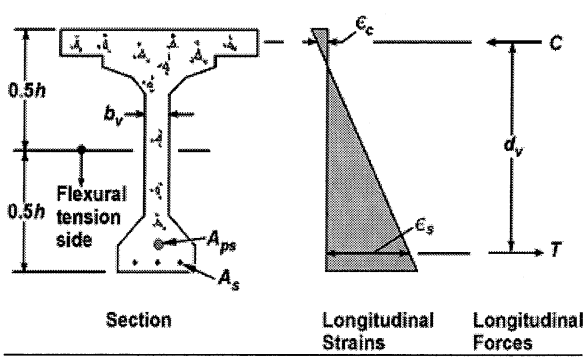


**Figure 5.8.3.4.2-2 Longitudinal Strain, $\varepsilon_s$ for Sections Containing Less than the Minimum Amount of Transverse Reinforcement.**



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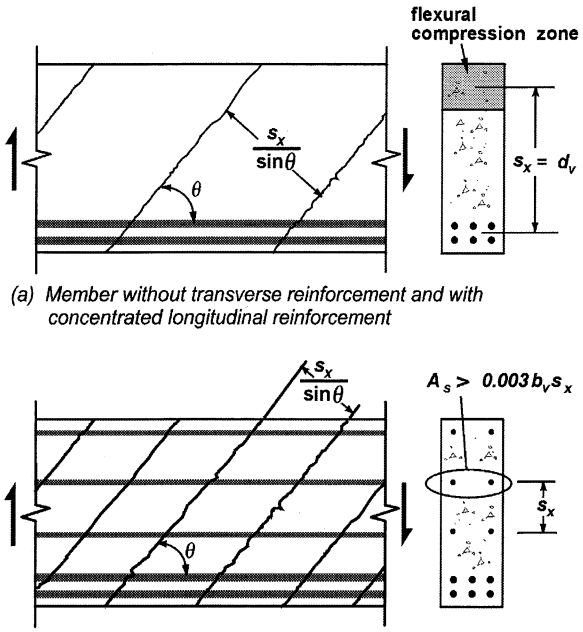


**Figure 5.8.3.4.2-3 Definition of Crack Spacing Parameter, $s_x$.**

The relationships for evaluating β and θ in Eqs. 1 and 2 are based on calculating the stresses that can be transmitted across diagonally cracked concrete. As the cracks become wider, the stress that can be transmitted decreases. For members containing at least the minimum amount of transverse reinforcement, it is assumed that the diagonal cracks will be spaced about 12.0 in. apart. For members without transverse reinforcement, the spacing of diagonal cracks inclined at θ° to the longitudinal reinforcement is assumed to be $s_x/\sin\theta$, as shown in Figure 3. Hence, deeper members having larger values of $s_x$ are calculated to have more widely spaced cracks and hence, cannot transmit such high shear stresses. The ability of the crack surfaces to transmit shear stresses is influenced by the aggregate size of the concrete. Members made from concretes that have a smaller maximum aggregate size will have a larger value of $s_{xe}$ and hence, if there is no transverse reinforcement, will have a smaller shear strength.

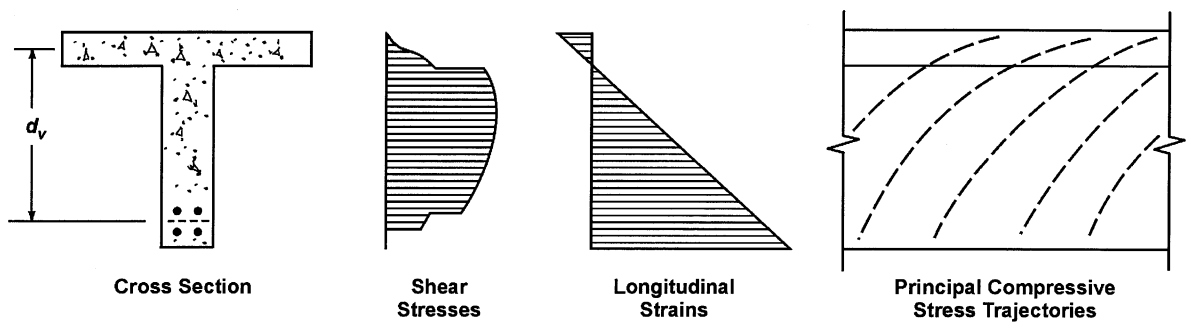


**Figure C5.8.3.4.2-1 Detailed Sectional Analysis to Determine Shear Resistance in Accordance with Article 5.8.3.1.**

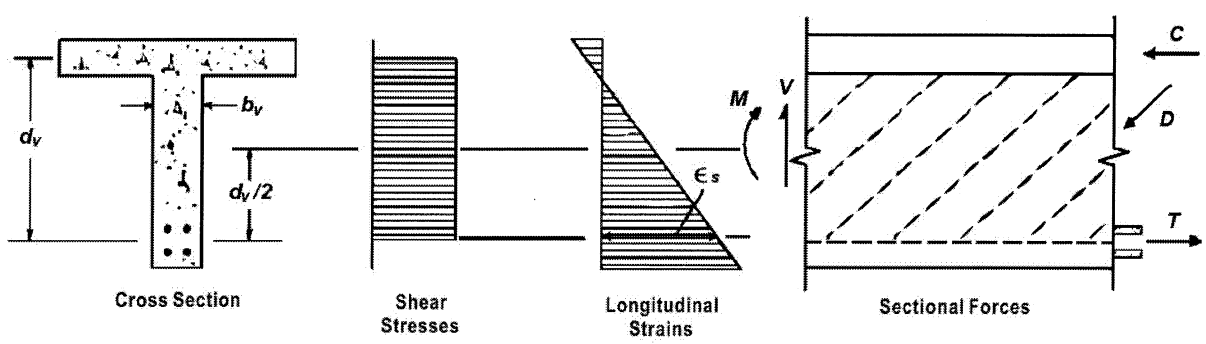


**Figure C5.8.3.4.2-2 More Direct Procedure to Determine Shear Resistance in Accordance with Article 5.8.3.4.2.**

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8.6/16



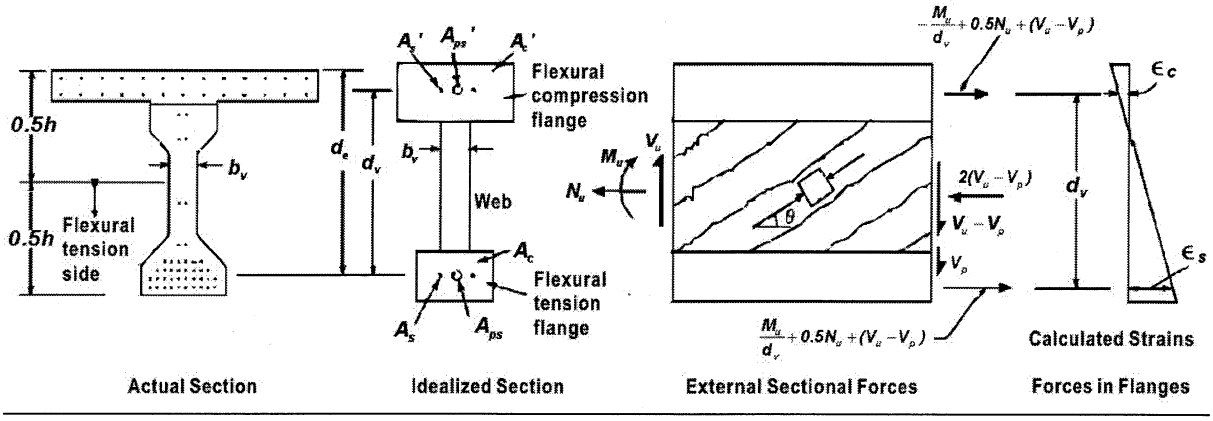


**Figure C5.8.3.4.2-3 More Accurate Calculation Procedure for Determining $\varepsilon_s$.**

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**URS**

Job _____ Project No. _____ Page ____ of ____

Description Cline Computed by RJB Sheet ____ of ____

Checked by _____ Date 9/29/09

Date _____

Reference

Node 120 Back

$$v = \frac{V_n - V_p}{b_w (jd)}$$

$$v = \frac{1815 - 1175}{(15'')(77.8'')} = 0.548 \text{ ksi}$$

$$\frac{v}{f'_c} = \frac{0.548}{5} = \underline{0.110}$$

$$\varepsilon_x = \frac{\left( \frac{M_u}{d_v} + 0.5 N_u + 0.5 \left| V_u - V_p \right| \cot\theta - A_{ps} f_{po} \right)}{2 \left( E_s A_s + E_{ps} A_{ps} \right)}$$

assume $\theta = 28°$ $-16951.42$

$$\varepsilon_x = \frac{\overset{177.37}{\frac{1147 \times 12}{77.60}} + 0.5 \overset{-13.00}{(-26)} + 0.5 \overset{601.83}{\left| 1815 - 1175 \right|} \overset{\cot 28° \; -17717.62}{\cot} - (93.744)(0.7)(27$$

$$\frac{}{2\left[(29000)(7.2) + (28500)(93.744)\right]}$$

5,761,008.

$$\varepsilon_x = \underline{-0.00294}$$

negative – use eq. B5.2-3

(assume ½ section for flexure)

$$\varepsilon_x = \frac{-16951.42}{\left\{ 2\left[(4074)(13174)(0.5)\right] + 5761008. \right\}} = -0.00029$$

$\times 1000$

$-0.29$

8.6/18



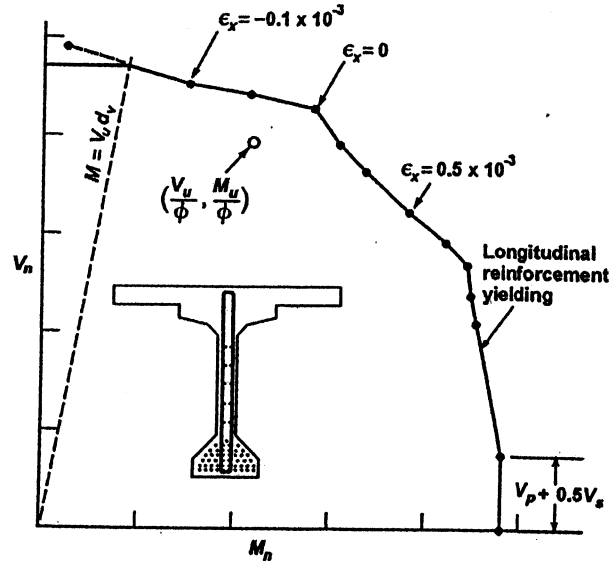


**Figure C5.8.3.4.2-6 Typical Shear-Moment Interaction Diagram.**

More details on the procedures used in deriving the tabulated values of θ and β are given in Collins and Mitchell (*1991*).

**Table 5.8.3.4.2-1 Values of θ and β for Sections with Transverse Reinforcement.**

| $\frac{v_u}{f'_c}$ | $\varepsilon_x \times 1{,}000$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ≤−0.20 | ≤−0.10 | ≤−0.05 | ≤0 | ≤0.125 | ≤0.25 | ≤0.50 | ≤0.75 | ≤1.00 |
| ≤0.075 | 22.3<br>6.32 | 20.4<br>4.75 | 21.0<br>4.10 | 21.8<br>3.75 | 24.3<br>3.24 | 26.6<br>2.94 | 30.5<br>2.59 | 33.7<br>2.38 | 36.4<br>2.23 |
| ≤0.100 | 18.1 19.25<br>3.79 3.59 | 20.4<br>3.38 | 21.4<br>3.24 | 22.5<br>3.14 | 24.9<br>2.91 | 27.1<br>2.75 | 30.8<br>2.50 | 34.0<br>2.32 | 36.7<br>2.18 |
| ≤0.125 | 19.9 20.9<br>3.18 3.09 | 21.9<br>2.99 | 22.8<br>2.94 | 23.7<br>2.87 | 25.9<br>2.74 | 27.9<br>2.62 | 31.4<br>2.42 | 34.4<br>2.26 | 37.0<br>2.13 |
| ≤0.150 | 21.6<br>2.88 | 23.3<br>2.79 | 24.2<br>2.78 | 25.0<br>2.72 | 26.9<br>2.60 | 28.8<br>2.52 | 32.1<br>2.36 | 34.9<br>2.21 | 37.3<br>2.08 |
| ≤0.175 | 23.2<br>2.73 | 24.7<br>2.66 | 25.5<br>2.65 | 26.2<br>2.60 | 28.0<br>2.52 | 29.7<br>2.44 | 32.7<br>2.28 | 35.2<br>2.14 | 36.8<br>1.96 |
| ≤0.200 | 24.7<br>2.63 | 26.1<br>2.59 | 26.7<br>2.52 | 27.4<br>2.51 | 29.0<br>2.43 | 30.6<br>2.37 | 32.8<br>2.14 | 34.5<br>1.94 | 36.1<br>1.79 |
| ≤0.225 | 26.1<br>2.53 | 27.3<br>2.45 | 27.9<br>2.42 | 28.5<br>2.40 | 30.0<br>2.34 | 30.8<br>2.14 | 32.3<br>1.86 | 34.0<br>1.73 | 35.7<br>1.64 |
| ≤0.250 | 27.5<br>2.39 | 28.6<br>2.39 | 29.1<br>2.33 | 29.7<br>2.33 | 30.6<br>2.12 | 31.3<br>1.93 | 32.8<br>1.70 | 34.3<br>1.58 | 35.8<br>1.50 |

−0.0002

+1.0000

8-6/19

URS

Project: Cline --Seg 6 EB
Description: Shear Strength Rating Ind Shear and Tran Bend with Increased Vc

Job No. 25626272.00001
Design: TSP
Check: Ind Chk

Page _____
Date: 6 / 17 / 2009
Date: / /

File Location: V:\Projects\Cline Avenue\Load Rating Analysis\Revised LL Long Rating\MathCad Revised Vc AASHTO Lanes\Seg 6 EB\

Node := 120 Position := Back $b_{voverride}$ := 15

## Objective

Calculations for Segmental Box Girder Load Rating--Shear Strength (HL-93 Operating Loading) considering Longitudinal Shear and Transverse Bending Independently--using finding of the Menn recommendations

## Codes and Specifications

- ASHTO LRFD Bridge Design Specifications--Customary US Units, 4th Edition, 2007.
- AASHTO Guide Manual for the Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Hightway Bridges Specifications--Customary US Units, First Edition, 2004, with Interim Specifications through 2005.
- AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges, Second Edition, 1999, with Interim Specifications through 2003.

## Unit & Function Definitions

$psf \equiv \frac{lbf}{ft^2}$ $pcf \equiv \frac{lbf}{ft^3}$ $ksf \equiv \frac{kip}{ft^2}$ $tons \equiv 2000lbf$ $kips \equiv kip$

## General Information

**Permanant Loads:**

| | | | | |
|---|---|---|---|---|
| $V_{dc_x} = 866 \cdot kips$ | $M_{dc_x} = 646 \cdot kip \cdot ft$ | $T_{dc_x} = -105\, ft \cdot kips$ | $N_{dc_x} = -1 \cdot kips$ | Dead Load |
| $V_{dw_x} = 101 \cdot kips$ | $M_{dw_x} = 96 \cdot kip \cdot ft$ | $T_{dw_x} = -31 \cdot kip \cdot ft$ | $N_{dw_x} = 1 \cdot kips$ | Superimposed Dead Load |
| $V_{psec_x} = 118 \cdot kips$ | $M_{psec_x} = 90 \cdot kip \cdot ft$ | $T_{psec_x} = -693 \cdot kip \cdot ft$ | $N_{psec_x} = 0 \cdot kips$ | Secondary PT |
| $V_{ptls_x} = 0 \cdot kips$ | $M_{ptls_x} = 0 \cdot kip \cdot ft$ | $T_{ptls_x} = 0 \cdot kip \cdot ft$ | $N_{ptls_x} = 0 \cdot kips$ | Secondary Loss PT |
| $V_{crsh_x} = -21\, kip$ | $M_{crsh_x} = 405 \cdot kip \cdot ft$ | $T_{crsh_x} = 2089 \cdot kip \cdot ft$ | $N_{crsh_x} = -52 \cdot kips$ | Creep & Shrinkage |

**Live Loads (HL-93):**

| | | | | |
|---|---|---|---|---|
| $V_{LLvmax_x} = 351 \cdot kips$ | $M_{LLvmax_x} = -72 \cdot kip \cdot ft$ | $T_{LLvmax_x} = -720 \cdot kip \cdot ft$ | $N_{LLvmax_x} = 0 \cdot kips$ | Max Live Load Shear |
| $V_{LLvmin_x} = -42 \cdot kips$ | $M_{LLvmin_x} = 88 \cdot kip \cdot ft$ | $T_{LLvmin_x} = 302 \cdot kip \cdot ft$ | $N_{LLvmin_x} = 4 \cdot kips$ | Min Live Load Shear |
| $V_{LLtmax_x} = 132 \cdot kips$ | $M_{LLtmax_x} = 614 \cdot kip \cdot ft$ | $T_{LLtmax_x} = 2361 \cdot kip \cdot ft$ | $N_{LLtmax_x} = 18 \cdot kips$ | Max Live Load Torsion |
| $V_{LLtmin_x} = 271 \cdot kips$ | $M_{LLtmin_x} = -499 \cdot kip \cdot ft$ | $T_{LLtmin_x} = -3559 \cdot kip \cdot ft$ | $N_{LLtmin_x} = -20 \cdot kips$ | Min Live Load Torsion |

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**Post Tensioning Forces:**

$V_{prim_x} = -1175 \cdot kips$ Primary PT Shear

$N_{prim_x} = -10778 \cdot kips$ Primary PT Axial Force

$M_{prim_x} = -864 \cdot kip \cdot ft$ Primary PT Moment

$N_{ptlo_x} = 1233 \cdot kips$ Primary PT Axial Force

**Temperature/Transient Loads:**

$V_{tu_x} = 39 \cdot kips$

$M_{tu_x} = -62 \cdot kip \cdot ft$

**Temperature/Transient Loads:**

$T_{tu_x} = 444 \cdot kip \cdot ft$

$N_{tu_x} = -3 \cdot kips$ Uniform Temperature

**Girder Properties / Reinforcement:**

$f_c := 5.0 \cdot ksi$ 28 day Concrete Strength

$\phi := 0.90$ Phi Factor for Shear

$\phi_b := 0.90$ Phi Factor for Transverse Bending

$A_{box_x} = 13174 \cdot in^2$ Area of Concrete Box Girder

$A_{o_x} = 40905 \cdot in^2$ Torsional Area of Box Girder

$n_{webs_x} = 3$ Number of Webs per Box

$A_{v_x} = 0.372 \cdot in^2$ Area of Shear Steel

$s := 12 \cdot in$ Spacing of Shear Steel

$f_y := 60 \cdot ksi$ Rebar Yield Strength

$f_{pu} := 270 \cdot ksi$ Post-Tensioning Steel Yield Str.

$$E_c := 33000 \cdot 0.145^{1.5} \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi = 4074 \cdot ksi$$

$E_s := 29000 \cdot ksi$ Elastic Modulus Mild Steel

$E_{ps} := 28500 \cdot ksi$ Elastic Modulus PT Steel

$cover := 1 \cdot in$ Transverse Bending Steel Cover

$d_b := 0.625 \cdot in$ Web Steel Diameter

$H_{box_x} = 108 \cdot in$ Height of Box

$y_{bot_x} = 67.433 \cdot in$ Centroid of Box Bottom

$b_{e_x} = 5.5 \cdot in$ Effective Width of Shear Flow Path

$b_{v_x} = 15 \cdot in$ Width of Single Web

$A_{b_x} = 0.271 \cdot in^2$ Area of Steel Req'd for Trans. Bend full width.

$A_{bd_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend full width.

$A_{bs_x} = 0.257 \cdot in^2$ Area of Steel Req'd for Trans. Bend restricted to striped lanes

$A_{bds_x} = 0.134 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend restricted to striped lanes

$A_{bn_x} = 0.0001 \cdot in^2$ Area of Steel Req'd for Trans. Bend no transverse bending

$A_{bdn_x} = 0.00001 \cdot in^2$ Area of Steel Req'd for Dead Trans. Bend no transverse bending

$A_{ps_x} = 93.744 \cdot in^2$ Area of Post-Tensioning Steel

$d_{t_x} = 101 \cdot in$ Depth for Torsion

$A_{s_x} = 7.2 \cdot in^2$ Area of Mild Steel on Flex Ten Side

$d_{s_x} = 106 \cdot in$ Depth of Mild Steel

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## Shear Strength Calculations: AASHTO LRFD Section 5.8--General Procedure

**Operating Load Combinations:**

**Maximum and Corresponding Shear Combinations:**

$$V_{uvmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmax_y}\right)$$

$$V_{uvmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLvmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLvmin_y}\right)$$

$$V_{utmax_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmax_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \cdot \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmax_y}\right)$$

$$V_{utmin_y} := 1.25 \cdot V_{dc_y} + 1.5 V_{dw_y} + 1.35 \cdot V_{LLtmin_y} + V_{psec_y} + V_{ptls_y} + 0.5 \cdot V_{crsh_y} + 0 \left|V_{tu_y}\right| \cdot \mathrm{sign}\left(V_{LLtmin_y}\right)$$

**Maximum and Corresponding Torsion Combinations:**

$$T_{uvmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmax_y}\right)$$

$$T_{uvmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLvmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLvmin_y}\right)$$

$$T_{utmax_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmax_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmax_y}\right)$$

$$T_{utmin_y} := 1.25 \cdot T_{dc_y} + 1.5 T_{dw_y} + 1.35 \cdot T_{LLtmin_y} + T_{psec_y} + T_{ptls_y} + 0.5 \cdot T_{crsh_y} + 0 \left|T_{tu_y}\right| \cdot \mathrm{sign}\left(T_{LLtmin_y}\right)$$

**Corresponding Moment Combinations:**

$$M_{uvmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmax_y}\right)$$

$$M_{uvmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLvmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLvmin_y}\right)$$

$$M_{utmax_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmax_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \cdot \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmax_y}\right)$$

$$M_{utmin_y} := 1.25 \cdot M_{dc_y} + 1.5 M_{dw_y} + 1.35 \cdot M_{LLtmin_y} + M_{psec_y} + M_{ptls_y} + 0.5 \cdot M_{crsh_y} + 0 \left|M_{tu_y}\right| \cdot \mathrm{sign}\left(M_{LLtmin_y}\right)$$

**Corresponding Axial Force Combinations:**

$$N_{uvmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmax_y}\right)$$

$$N_{uvmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLvmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLvmin_y}\right)$$

$$N_{utmax_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmax_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmax_y}\right)$$

$$N_{utmin_y} := 1.25 \cdot N_{dc_y} + 1.5 N_{dw_y} + 1.35 \cdot N_{LLtmin_y} + N_{psec_y} + N_{ptls_y} + 0.5 \cdot N_{crsh_y} + 0 \left|N_{tu_y}\right| \cdot \mathrm{sign}\left(N_{LLtmin_y}\right)$$

| | | | |
|---|---|---|---|
| $V_{uvmax_x} = 1815 \cdot kips$ | $T_{uvmax_x} = -798 \cdot kip \cdot ft$ | $M_{uvmax_x} = 1147\, ft \cdot kips$ | $N_{uvmax_x} = -26 \cdot kips$ |
| $V_{uvmin_x} = 1285 \cdot kips$ | $T_{uvmin_x} = 581 \cdot kip \cdot ft$ | $M_{uvmin_x} = 1363\, ft \cdot kips$ | $N_{uvmin_x} = -20 \cdot kips$ |
| $V_{utmax_x} = 1520 \cdot kips$ | $T_{utmax_x} = 3361 \cdot kip \cdot ft$ | $M_{utmax_x} = 2073\, ft \cdot kips$ | $N_{utmax_x} = -1 \cdot kips$ |
| $V_{utmin_x} = 1707 \cdot kips$ | $T_{utmin_x} = -4631 \cdot kip \cdot ft$ | $M_{utmin_x} = 570\, ft \cdot kips$ | $N_{utmin_x} = -53 \cdot kips$ |

***Calculate Variables Used for All Live Load Conditions:***

$$f_{pc_y} := \frac{N_{prim_y}}{A_{box_y}} + \frac{N_{ptlo_y}}{A_{box_y}} + \frac{N_{psec_y}}{A_{box_y}} + \frac{N_{ptls_y}}{A_{box_y}}$$

$f_{pc_x} = -0.725\,ksi$

$$K := \left| \begin{array}{l} \text{for } i \in 1..\text{rows}(DC) \\ \quad K_{1_i} \leftarrow \sqrt{1 - \dfrac{f_{pc_i}}{0.0632 \cdot ksi \cdot \sqrt{\dfrac{f_c}{ksi}}}} \\ \quad K_{2_i} \leftarrow 2 \\ \quad K_i \leftarrow \min\left(K_{1_i}, K_{2_i}\right) \\ K \end{array} \right.$$

$K_x = 2$

$f_{po} := 0.7 \cdot f_{pu}$

$$T_{cr_y} := 0.0632 \cdot K_y \cdot \sqrt{\frac{f_c}{ksi}} \cdot ksi \cdot \left(2 \cdot A_{o_y} \cdot b_{e_y}\right)$$

$T_{cr_x} = 10598 \cdot kip \cdot ft$

$$d_{e_y} := \frac{\max\left(y_{bot_y} - \dfrac{M_{prim_y}}{N_{prim_y}}, H_{box_y} - y_{bot_y} + \dfrac{M_{prim_y}}{N_{prim_y}}\right) \cdot A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y \cdot d_{s_y}}{A_{ps_y} \cdot f_{po} + A_{s_y} \cdot f_y}$$

$d_{e_x} = 67.412 \cdot in$

$$d_{v_y} := \max\left(0.72 \cdot H_{box_y}, 0.9\, d_{e_y}\right)$$

$d_{v_x} = 77.76 \cdot in$

***Determing the Shear Requirement per Web--Max Pos Shear with Corresponding Torison***

$$\varepsilon_{svmax} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{uvmax_i}\right|}{d_{v_i}} + 0.5 \cdot N_{uvmax_i} + \left|\left|V_{uvmax_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if} \quad \varepsilon_1 \ge 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$\varepsilon_{svmax_x} = -0.0004$

$\theta_{vmax_y} := \left(29 + 3500 \cdot \varepsilon_{svmax_y}\right) \cdot deg$ $\qquad \theta_{vmax_x} = 27.6 \cdot deg$

$\beta_{vmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmax_y}\right)}$ $\qquad \beta_{vmax_x} = 6.857$

$V_{cvmax_y} := 0.0316 \cdot \beta_{vmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmax_x} = 565.149 \cdot kips$

$UseTorsionMaxShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxShear_x = \text{"No"}}$

$V_{dwebvmax_y} := \dfrac{V_{uvmax_y} - 1.35 \cdot V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|T_{uvmax_y} - 1.35 \cdot T_{LLvmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebvmax_x} = 447.167\,kip$

$V_{LLwebvmax_y} := \dfrac{1.35\,V_{LLvmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{\left|1.35 \cdot T_{LLvmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxShear_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebvmax_x} = 157.95 \cdot kips$

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$$RF_{vpos} := \text{for } i \in y$$

$$V_{s_i} \leftarrow \frac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmax_i})}$$

$$V_p \leftarrow |V_{prim_i}|$$

$$\phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmax_i} + V_{s_i} + \frac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases}$$

$$RF_{1_i} \leftarrow \frac{\phi V_{n_i} - V_{dwebvmax_i}}{V_{LLwebvmax_i}}$$

$$RF_{2_i} \leftarrow \frac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}}$$

$$RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases}$$

$$RF_{i,2} \leftarrow RF_{1_i}$$

$$RF_{i,3} \leftarrow RF_{2_i}$$

$$RF$$

$$RF_{vpos_{x,1}} = 1.737$$

***Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison***

$$\varepsilon_{svmin} := \text{for } i \in y$$

$$\varepsilon_1 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}}$$

$$\varepsilon_2 \leftarrow \frac{\left( \frac{|M_{uvmin_i}|}{d_{v_i}} + 0.5 \cdot N_{uvmin_i} + \left| |V_{uvmin_i}| - |V_{prim_i}| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}}$$

$$\varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0$$

$$\varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \quad \text{otherwise}$$

$$\varepsilon$$

$$\varepsilon_{svmin_x} = -0.0004$$

$\theta_{vmin_y} := \left(29 + 3500 \cdot \varepsilon_{svmin_y}\right) \cdot deg$ $\qquad \theta_{vmin_x} = 27.6 \cdot deg$

$\beta_{vmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{svmin_y}\right)}$ $\qquad \beta_{vmin_x} = 6.857$

$V_{cvmin_y} := 0.0316 \cdot \beta_{vmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{cvmin_x} = 565.149 \cdot kips$

$UseTorsionMinShear := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{uvmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMinShear_x = \text{"No"}}$

$V_{dwebvmin_y} := \dfrac{V_{uvmin_y} - 1.35 \cdot V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|T_{uvmin_y} - 1.35 \cdot T_{LLvmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{dwebvmin_x} = 447.167\,kip$

$V_{LLwebvmin_y} := \dfrac{1.35\, V_{LLvmin_y}}{n_{webs_y}} - \left| \begin{array}{ll} \dfrac{\left|1.35 \cdot T_{LLvmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} & \text{if} \quad UseTorsionMinShear_y = \text{"Yes"} \\ (0 \cdot kips) & \text{otherwise} \end{array} \right.$

$V_{LLwebvmin_x} = -18.9 \cdot kips$

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$$RF_{vneg} := \text{for } i \in y \;\; \begin{array}{l} V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan(\theta_{vmin_i})} \\ V_p \leftarrow \left| V_{prim_i} \right| \\ \phi V_{n_i} \leftarrow \phi \cdot \left( V_{cvmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \begin{cases} 1 & \text{if } V_{LLwebvmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{cases} \\ RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebvmin_i}}{V_{LLwebvmin_i}} \\ RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ RF_{i,1} \leftarrow \begin{cases} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min(RF_{1_i}, RF_{2_i}) & \text{otherwise} \end{cases} \\ RF_{i,2} \leftarrow RF_{1_i} \\ RF_{i,3} \leftarrow RF_{2_i} \end{array}$$

$$RF$$

$$RF_{vneg_{x,1}} = 1.737$$

***Determing the Shear Requirement per Web--Max Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmax} := \text{for } i \in y \;\; \begin{array}{l} \varepsilon_1 \leftarrow \dfrac{\left( \dfrac{\left| M_{utmax_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| \left| V_{utmax_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \varepsilon_2 \leftarrow \dfrac{\left( \dfrac{\left| M_{utmax_i} \right|}{d_{v_i}} + 0.5 \cdot N_{utmax_i} + \left| \left| V_{utmax_i} \right| - \left| V_{prim_i} \right| \right| - A_{ps_i} \cdot f_{po} \right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \varepsilon_i \leftarrow \varepsilon_1 \;\; \text{if } \varepsilon_1 \geq 0 \\ \varepsilon_i \leftarrow \max(\varepsilon_2, -0.0004) \;\; \text{otherwise} \end{array}$$

$$\varepsilon$$

$$\varepsilon_{stmax_x} = -0.0004$$

$\theta_{tmax_y} := \left(29 + 3500 \cdot \varepsilon_{stmax_y}\right) \cdot deg$ $\qquad \theta_{tmax_x} = 27.6 \cdot deg$

$\beta_{tmax_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmax_y}\right)}$ $\qquad \beta_{tmax_x} = 6.857$

$V_{ctmax_y} := 0.0316 \cdot \beta_{tmax_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmax_x} = 565.149 \cdot kips$

$UseTorsionMaxTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmax_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$ $\qquad \boxed{UseTorsionMaxTorsion_x = \text{"Yes"}}$

$T_{vmax_y} := sign\left(V_{LLtmax_y}\right)$

$V_{dwebtmax_y} := \dfrac{V_{utmax_y} - 1.35 \cdot V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|T_{utmax_y} - 1.35 \cdot T_{LLtmax_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Y} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{dwebtmax_x} = 449.741\ kip$

$V_{LLwebtmax_y} := \dfrac{1.35\, V_{LLtmax_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmax_y} \left|1.35 \cdot T_{LLtmax_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMaxTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$

$V_{LLwebtmax_x} = 106.62 \cdot kips$

$$RF_{tpos} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmax_i}\right)} \\ \quad V_p \leftarrow \left|V_{prim_i}\right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left(V_{ctmax_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}}\right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmax_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmax_i}}{V_{LLwebtmax_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$RF_{tpos_{x,1}} = 1.737$$

***Determing the Shear Requirement per Web--Min Pos Torsion with Corresponding Shear***

$$\varepsilon_{stmin} := \left| \begin{array}{l} \text{for } i \in y \\ \quad \varepsilon_1 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i}} \\ \quad \varepsilon_2 \leftarrow \dfrac{\left(\dfrac{\left|M_{utmin_i}\right|}{d_{v_i}} + 0.5 \cdot N_{utmin_i} + \left|\left|V_{utmin_i}\right| - \left|V_{prim_i}\right|\right| - A_{ps_i} \cdot f_{po}\right)}{E_s \cdot A_{s_i} + E_{ps} \cdot A_{ps_i} + 0.5 \cdot E_c \cdot A_{box_i}} \\ \quad \varepsilon_i \leftarrow \varepsilon_1 \quad \text{if } \varepsilon_1 \geq 0 \\ \quad \varepsilon_i \leftarrow \max\left(\varepsilon_2, -0.0004\right) \quad \text{otherwise} \\ \varepsilon \end{array} \right.$$

$$\varepsilon_{stmin_x} = -0.0004$$

$\theta_{tmin_y} := \left(29 + 3500 \cdot \varepsilon_{stmin_y}\right) \cdot deg$ $\qquad \theta_{tmin_x} = 27.6 \cdot deg$

$\beta_{tmin_y} := \dfrac{4.8}{\left(1 + 750 \cdot \varepsilon_{stmin_y}\right)}$ $\qquad \beta_{tmin_x} = 6.857$

$V_{ctmin_y} := 0.0316 \cdot \beta_{tmin_y} \cdot \sqrt{\dfrac{f_c}{ksi}} \cdot ksi \cdot b_{v_y} \cdot d_{v_y}$ $\qquad V_{ctmin_x} = 565.149 \cdot kips$

$$UseTorsionMinTorsion := \left| \begin{array}{l} \text{for } i \in y \\ \quad \left| \begin{array}{l} T_u \leftarrow \left|T_{utmin_i}\right| \\ z_i \leftarrow \text{"Yes"} \quad \text{if} \quad \phi \cdot \dfrac{T_{cr_i}}{3} < T_u \\ z_i \leftarrow \text{"No"} \quad \text{otherwise} \end{array} \right. \\ z \end{array} \right.$$

$UseTorsionMinTorsion_x = \text{"Yes"}$

$T_{vmin_y} := sign\left(V_{LLtmin_y}\right)$

$$V_{dwebtmin_y} := \frac{V_{utmin_y} - 1.35 \cdot V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|T_{utmin_y} - 1.35 \cdot T_{LLtmin_y}\right| \cdot d_{t_y}}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{dwebtmin_x} = 449.741\ kip$

$$V_{LLwebtmin_y} := \frac{1.35\, V_{LLtmin_y}}{n_{webs_y}} + \left| \begin{array}{l} \dfrac{T_{vmin_y}\left|1.35 \cdot T_{LLtmin_y} \cdot d_{t_y}\right|}{2 \cdot A_{o_y}} \quad \text{if} \quad UseTorsionMinTorsion_y = \text{"Yes"} \\ (0 \cdot kips) \quad \text{otherwise} \end{array} \right.$$

$V_{LLwebtmin_x} = 193.13 \cdot kips$

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$$RF_{tneg} := \left| \begin{array}{l} \text{for } i \in y \\ \quad V_{s_i} \leftarrow \dfrac{2 \cdot A_{v_i} \cdot f_y \cdot d_{v_i}}{s \cdot \tan\left(\theta_{tmin_i}\right)} \\ \quad V_p \leftarrow \left| V_{prim_i} \right| \\ \quad \phi V_{n_i} \leftarrow \phi \cdot \left( V_{ctmin_i} + V_{s_i} + \dfrac{V_p}{n_{webs_i}} \right) \cdot \left| \begin{array}{ll} 1 & \text{if } V_{LLwebtmin_i} \geq 0 \cdot kips \\ (-1) & \text{otherwise} \end{array} \right. \\ \quad RF_{1_i} \leftarrow \dfrac{\phi V_{n_i} - V_{dwebtmin_i}}{V_{LLwebtmin_i}} \\ \quad RF_{2_i} \leftarrow \dfrac{A_{v_i} - A_{bd_i}}{A_{b_i} - A_{bd_i}} \\ \quad RF_{i,1} \leftarrow \left| \begin{array}{ll} RF_{2_i} & \text{if } REBAR_{i,6} = \text{"P"} \\ \min\left(RF_{1_i}, RF_{2_i}\right) & \text{otherwise} \end{array} \right. \\ \quad RF_{i,2} \leftarrow RF_{1_i} \\ \quad RF_{i,3} \leftarrow RF_{2_i} \\ RF \end{array} \right.$$

$$\boxed{RF_{tneg_{x,1}} = 1.737}$$

$$RF_{all} := \left| \begin{array}{l} \text{for } i \in y \\ \quad RF_{i,1} \leftarrow \min\left(RF_{vpos_{i,1}}, RF_{vneg_{i,1}}, RF_{tpos_{i,1}}, RF_{tneg_{i,1}}\right) \\ \quad RF_{i,2} \leftarrow \min\left(RF_{vpos_{i,2}}, RF_{vneg_{i,2}}, RF_{tpos_{i,2}}, RF_{tneg_{i,2}}\right) \\ \quad RF_{i,3} \leftarrow \min\left(RF_{vpos_{i,3}}, RF_{vneg_{i,3}}, RF_{tpos_{i,3}}, RF_{tneg_{i,3}}\right) \\ RF \end{array} \right.$$

$$Limit := \left| \begin{array}{l} \text{for } i \in y \\ \quad L_i \leftarrow 1 \\ L \end{array} \right. \qquad DLLimit := \left| \begin{array}{l} \text{for } i \in y \\ \quad D_i \leftarrow 0 \\ D \end{array} \right.$$

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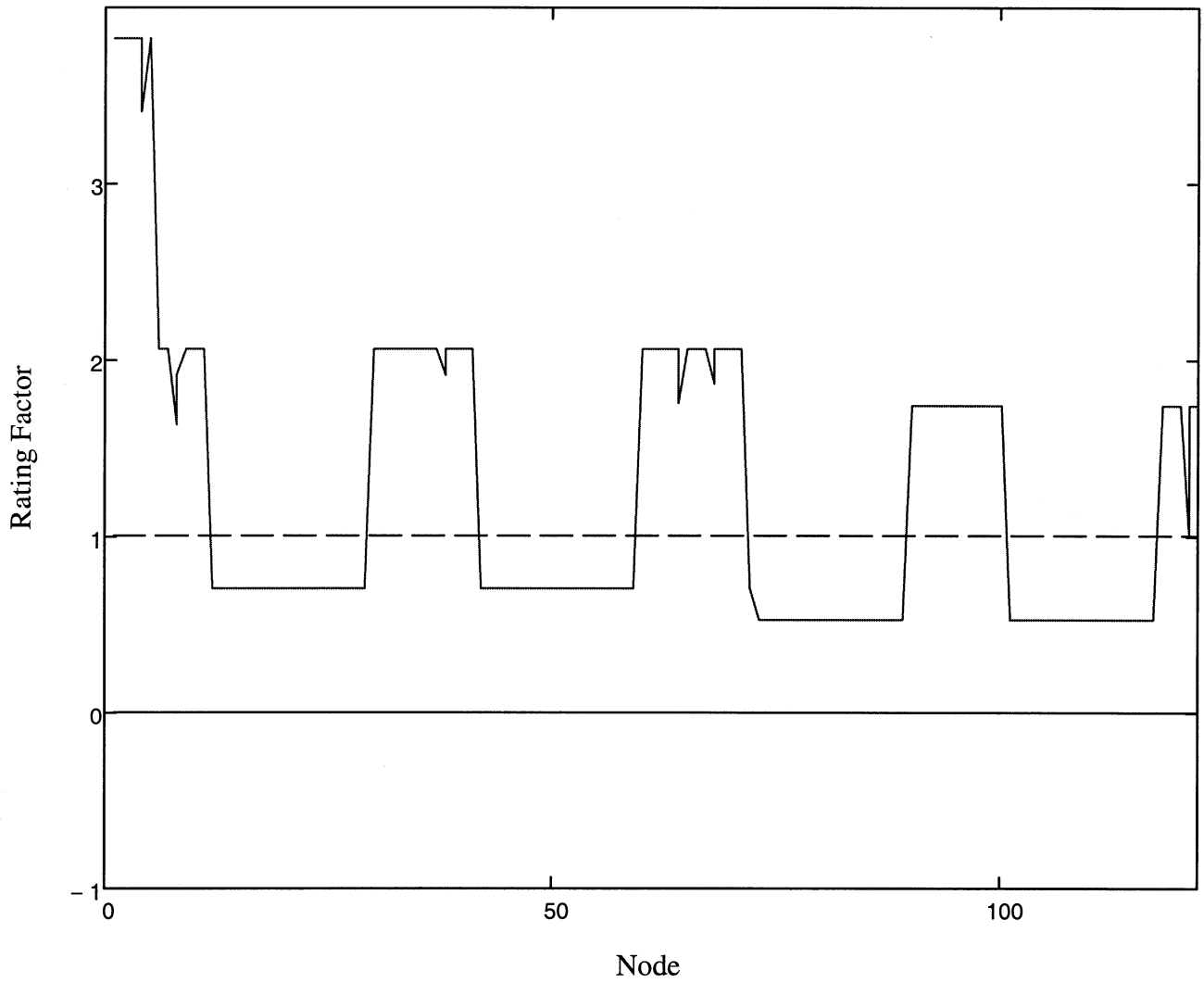
Rating Factor Plot Considering Long. Shear and Tran Bend Independently




—— Rating Factor
— – Limit
—— Dead Load Limit

Minimum Rating Factor for Longitudinal Shear is $minRF_1 = 0.993$ at node $minRF_2 = 121$ $minRF_4 = \text{"Back"}$

Minimum Rating Factor for Transverse Bending is $minRF_3 = 0.528$

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## *Determine the Rating Factor using the Method of Combining Transverse Bending and Shear per Menn to Verify Longitudinal Shear and Transverse Bending Act Independently*

### *Determing the Shear Requirement per Web--Min Pos Shear with Corresponding Torison*

$d_y := PROPS_{y,7} \cdot in - cover - d_b$ Use the web width used for Transverse Bending

$b_{bend} := 12 \cdot in$ Unit Length of Web

$V_{p_y} := \frac{V_{prim_y}}{n_{webs_y}}$

$m_{r_y} := \phi_b \cdot A_{b_y} \cdot f_y \cdot \left( d_y - \frac{A_{b_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $m_{r_x} = 178.893 \cdot kip \cdot in$

$m_{rd_y} := \phi_b \cdot A_{bd_y} \cdot f_y \cdot \left( d_y - \frac{A_{bd_y} \cdot f_y}{2 \cdot 0.85 \cdot f_c \cdot b_{bend}} \right)$ $V_{p_x} = -391.667\,kip$ $m_{rd_x} = 89.239 \cdot kip \cdot in$

$V_{prim_x} = -1.175 \times 10^3\,kip$

$b_{o_y} := b_{v_y} - 2 \cdot cover - d_b$ $b_{o_x} = 12.375 \cdot in$

$b' := cover + \frac{1}{2} \cdot d_b$ $b' = 1.313 \cdot in$

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \le 4 \cdot ksi \\ \left[ 0.85 - 0.05 \cdot \left( \frac{f_c - 4 \cdot ksi}{ksi} \right) \right] & \text{if } 4 \cdot ksi < f_c \le 8 \cdot ksi \\ 0.65 & \text{otherwise} \end{cases}$$ $\beta_1 = 0.8$

$b_{1_y} := \frac{A_{b_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1_x} = 0.319 \cdot in$

$b_{1d_y} := \frac{A_{bd_y} \cdot f_y}{0.85 \cdot f_c \cdot b_{bend}}$ $b_{1d_x} = 0.158 \cdot in$

Using the Method prescribed by Menn--develop an interaction diagram to show the capacity of the web for Combined Transverse Bending and Longitudinal Shear

Case I: Transverse Bending Predominates--Use the maximum bending capacity and determine the resulting shear capacity

$y_{1_y} := b_{o_y} + b' - \frac{b_{1_y}}{2}$ $y_{1_x} = 13.528 \cdot in$

$F_{cu_y} := A_{v_y} \cdot f_y$ $F_{cu_x} = 22.32 \cdot kips$

$\phi M_{n_1} := \phi \cdot \left( F_{cu_x} \cdot y_{1_x} \right)$ $\phi M_{n_1} = 22.646 \cdot kip \cdot ft$

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$\phi V_{n_1} := A_{v_x} \cdot f_y - F_{cu_x}$ $\phi V_{n_1} = 0 \cdot kips$

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Case II: Shear Predominates--Calculate the resulting bending capacity and longitudinal shear when the net force in one bar is equal to 0

$B_{r2_y} := A_{v_y} \cdot f_y$ $\qquad B_{r2_x} = 22.32 \cdot kips$

$V_{s2_y} := \dfrac{A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}{s}$ $\qquad V_{s2_x} = 276.659 \cdot kips$

$\phi V_{n2_y} := \phi \cdot \left(V_{cvmax_y} + V_{s2_y} + \left|V_{p_y}\right|\right)$ $\qquad \phi V_{n2_x} = 1.11 \times 10^3 \cdot kips$

$b_{wreq2_y} := \dfrac{V_{s2_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq2_x} = 0.438 \cdot in$

$\phi M_{n_2} := \min\left[\phi \cdot \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s2_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq2_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_2} = 22.547 \cdot kip \cdot ft$

Case III: Shear Predominates--Use the maximum shear capacity and determine the resulting moment capacity

$V_{s3_y} := \dfrac{2 A_{v_y} \cdot f_y \cdot d_{v_y} \cdot \cot(\theta_{vmin_y})}{s}$ $\qquad V_{s3_x} = 553.317 \cdot kips$

$\phi V_{n_3} := \phi \cdot \left(V_{cvmax_x} + V_{s3_x} + \left|V_{p_x}\right|\right)$ $\qquad \phi V_{n_3} = 1.359 \times 10^3 \cdot kips$

$b_{wreq3_y} := \dfrac{V_{s3_y}}{0.85 \cdot f_c \cdot d_{v_y} \cdot \cot(\theta_{vmax_y})}$ $\qquad b_{wreq3_x} = 0.875 \cdot in$

$\phi M_{n_3} := \min\left[\phi \left[A_{v_x} \cdot f_y \cdot b_{o_x} - \dfrac{V_{s3_x} \cdot s}{d_{v_x} \cdot \cot(\theta_{vmax_x})} \cdot \left(\dfrac{b_{wreq3_x}}{2} - b'\right)\right], \phi M_{n_1}\right]$ $\qquad \phi M_{n_3} = 22.646 \cdot kip \cdot ft$

Derive the Interaction Diagram:

$$\phi V_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} V_{n_i} \leftarrow \phi V_{n_i} \\ V_{n_{7-i}} \leftarrow \phi V \end{array} \right. \\ V_n \end{array} \right. \qquad \phi M_n := \left| \begin{array}{l} \text{for } i \in 1..3 \\ \quad \left| \begin{array}{l} M_{n_i} \leftarrow \phi M_{n_i} \\ M_{n_{7-i}} \leftarrow -\phi M_n \end{array} \right. \\ M_n \end{array} \right. \qquad M_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} M_{u_i} \leftarrow m_{rd_x} \\ M_{u_{i+1}} \leftarrow m_{r_x} \end{array} \right. \\ M_u \end{array} \right. \qquad V_{u1} := \left| \begin{array}{l} \text{for } i \in 1 \\ \quad \left| \begin{array}{l} V_{u_i} \leftarrow \left|V_d\right| \\ V_{u_{i+1}} \leftarrow \left|V_d + V_{LL}\right| \end{array} \right. \\ V_u \end{array} \right.$$

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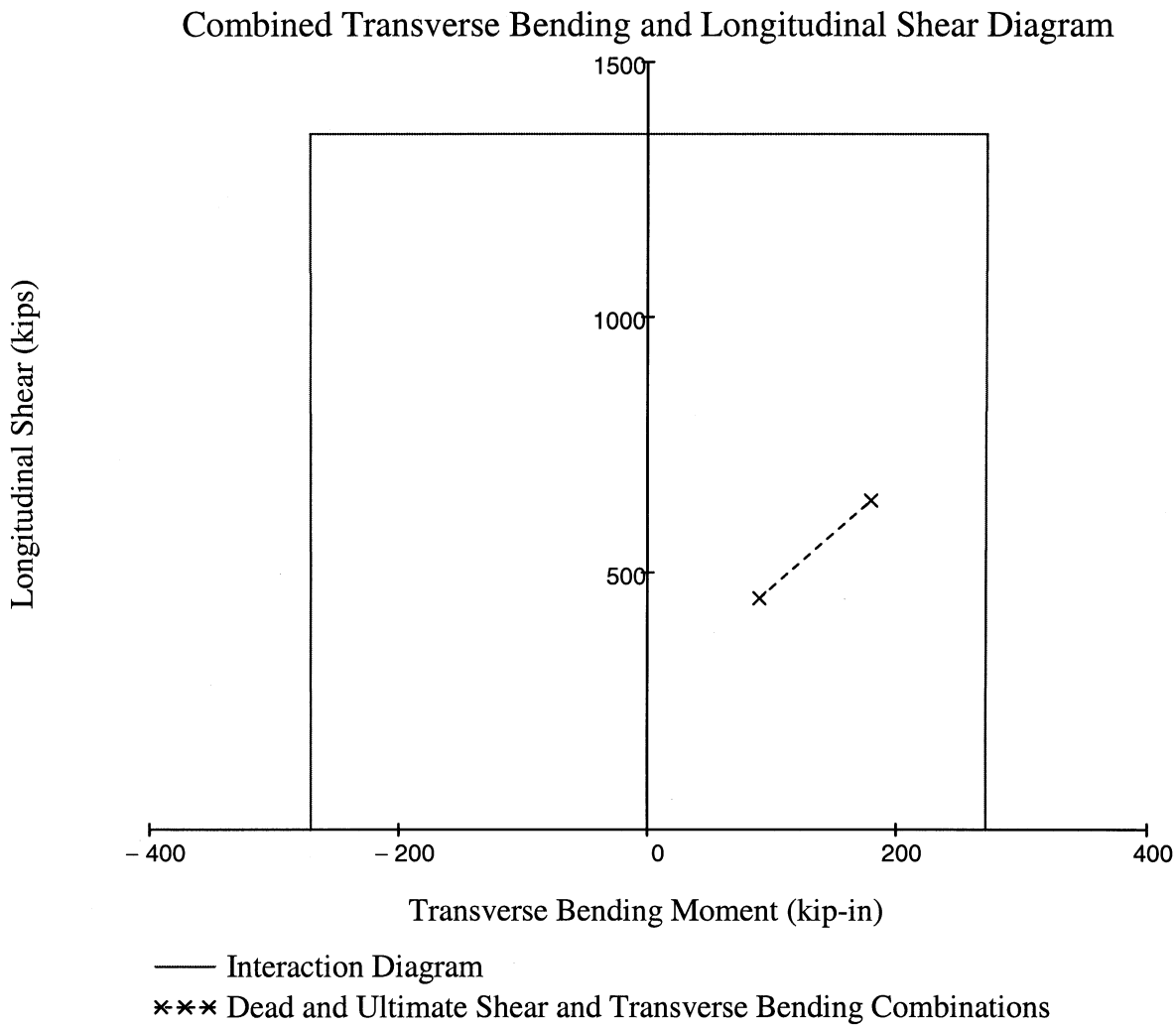


The interaction diagram above shows that the longitudinal shear and transverse bending have not interaction--they are acting independently therefore the rating factors may be calculated seperately.

$$RF_{bend} := \frac{\phi M_{n_1} - m_{rd_x}}{m_{r_x} - m_{rd_x}}$$

$RF_{bend} = 2.036$

$$RF_{shear} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebvmax_x}\right|}{\left|V_{LLwebvmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebvmin_x}\right|}{\left|V_{LLwebvmin_x}\right|}\right)$$

$RF_{shear} = 5.774$

$$RF_{torsion} := \min\left(\frac{\phi V_{n_3} - \left|V_{dwebtmax_x}\right|}{\left|V_{LLwebtmax_x}\right|}, \frac{\phi V_{n_3} - \left|V_{dwebtmin_x}\right|}{\left|V_{LLwebtmin_x}\right|}\right)$$

$RF_{torsion} = 4.709$