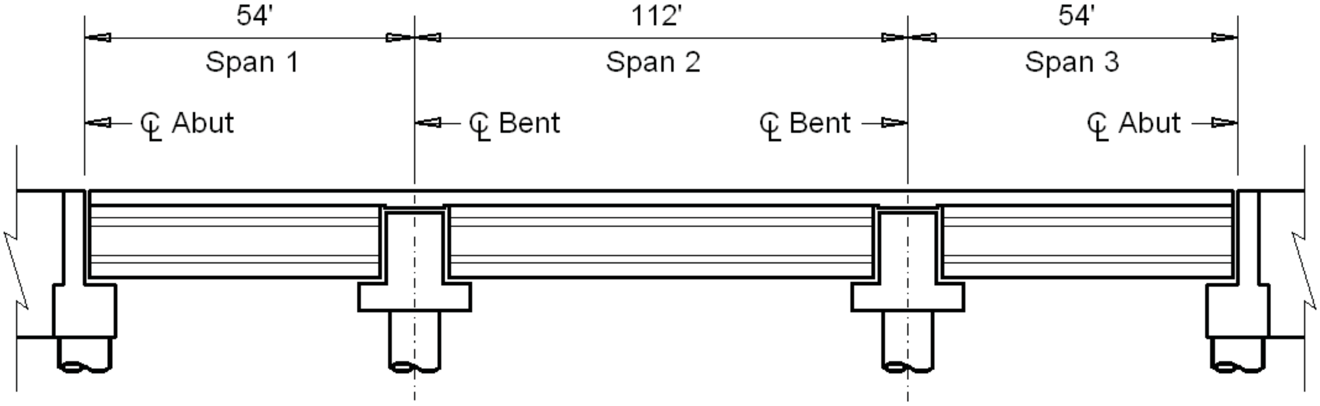
County: Any Hwy: Any Design: BRG Date: 6/2010

Inverted Tee Bent Cap Design Example

Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 5th Ed. (2010) as prescribed by TxDOT Bridge Design Manual - LRFD (May 2009).

# Design Parameters




## Span 1

54' Type TX54 Girders (0.851 $^{k}/_{ft}$)

6 Girders Spaced @ 8.00' with 3' overhangs
2" Haunch

## Span 2

112' Type TX54 Girders (0.851 $^{k}/_{ft}$)

6 Girders Spaced @ 8.00' with 3' overhangs
3.75" Haunch

## Span 3

54' Type TX54 Girders (0.851 $^{k}/_{ft}$)

6 Girders Spaced @ 8.00' with 3' overhangs
2" Haunch

## All Spans

Deck is 46ft wide
Type T551 Rail (0.382k/ft)
8" Thick Slab (0.100 ksf)
Assume 2" Overlay @ 140 pcf (0.023 ksf)
Use Class "C" Concrete

$f'_c$=3.60 ksi

$w_c$=150 pcf (for weight)

$w_c$=145 pcf (for Modulus of Elasticity calculation)

Grade 60 Reinforcing

$F_y$=60 ksi

## Bents

Use 36" Diameter Columns (Typical for Type TX54 Girders)

*"AASHTO LRFD" refers to the AASHTO LRFD Bridge Design Specification, 5th Ed. (2010)*

*"BDM-LRFD" refers to the TxDOT Bridge Design Manual - LRFD (May 2009)*

*"TxSP" refers to TxDOT guidance, recommendations, and standard practice.*

*"Furlong & Mirza" refers to "Strength and Servicability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion", Center for Highway Research Research Report No. 153-1F, The University of Texas at Austin, August 1974*

*The basic bridge geometry can be found on the Bridge Layout located in the Appendices.*

*(TxSP)*

*(BDM-LRFD, Ch. 4, Sect. 5, Materials)*

*(BDM-LRFD, Ch. 4, Sect. 5, Materials)*

## Design Parameters (Con't)

### Define Variables

| Back Span | Forward Span | |
|---|---|---|
| $Span1 = 54ft$ | $Span2 = 112ft$ | *Span Length* |
| $GdrSpa1 = 8ft$ | $GdrSpa2 = 8ft$ | *Girder Spacing* |
| $GdrNo1 = 6$ | $GdrNo2 = 6$ | *Number of Girders in Span* |
| $GdrWt1 = 0.851klf$ | $GdrWt2 = 0.851klf$ | *Weight of Girder* |
| $Haunch1 = 2in$ | $Haunch2 = 3.75in$ | *Size of Haunch* |

Bridge

| | |
|---|---|
| $Skew = 0deg$ | *Skew of Bents* |
| $BridgeW = 46ft$ | *Width of Bridge Deck* |
| $RdwyW = 44ft$ | *Width of Roadway* |
| $GirderD = 54in$ | *Depth of Type TX54 Girder* |
| $BrgSeat = 1.5in$ | *Bearing Seat Buildup* |
| $BrgPad = 2.75in$ | *Bearing Pad Thickness* |
| $SlabThk = 8in$ | *Thickness of Bridge Slab* |
| $OverlayThk = 2in$ | *Thickness of Overlay* |
| $RailWt = 0.382klf$ | *Weight of Rail* |
| $w_c = 0.150kcf$ | *Unit Weight of Concrete for Loads* |
| $W_{Olay} = 0.140kcf$ | *Unit Weight of Overlay* |

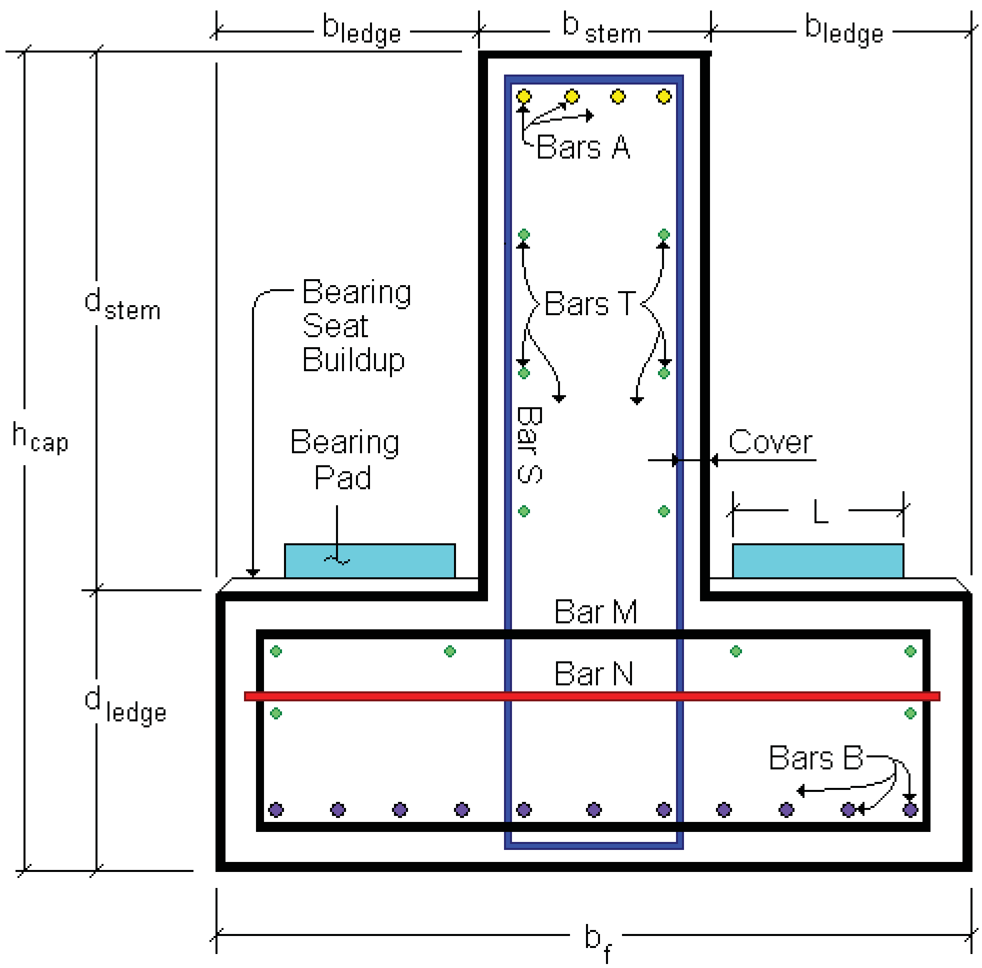
Bents

| | | |
|---|---|---|
| $f_c = 3.60ksi$ | | *Concrete Strength* |
| $w_{cE} = 0.145kcf$ | | *Unit Weight of Concrete for $E_c$* |
| $E_c = 33,000 \cdot w_{cE}^{1.5} \cdot \sqrt{f_c}$ | $E_c = 3457 \cdot ksi$ | *Modulus of Elasticity of Concrete, (AASHTO LRFD Eq. 5.4.2.4-1)* |
| $f_y = 60ksi$ | | *Yield Strength of reinforcement* |
| $E_s = 29000ksi$ | | *Modulus of Elasticity of Steel* |
| $D_{column} = 36in$ | | *Diameter of Columns* |

Other Variables

| | |
|---|---|
| $IM = 33\%$ | *Dynamic load allowance, (AASHTO LRFD Table 3.6.2.1-1)* |

## Determine Cap Dimensions




Section View

**Stem Width**

$b_{stem} = D_{column} + 3in$ $\qquad b_{stem} = 39 \cdot in$

*The stem is typically at least 3" wider than the Diameter of the Column (36") to allow for the extension of the column reinforcement into the Cap. (TxSP)*

**Stem Height**

Distance From Top of Slab to Top of Ledge

$D_{Slab\_to\_Ledge} = SlabThk + Haunch2 + GirderD + BrgPad + BrgSeat$

*Haunch 2 is the larger of the two haunches.*

$D_{Slab\_to\_Ledge} = 70.00 \cdot in$

$StemHaunch = 3.75 \cdot in$

*The top of the stem must be 2.5" below the bottom of the slab. (BDM-LRFD, Ch. 4, Sect. 5, Geometric Constraints) Accounting for the 1/2" of bituminus fiber, the top of the stem must have at least 2" of haunch on it, but the haunch should not be less than either of the haunches of the adjacent spans.*

$d_{stem} = D_{Slab\_to\_Ledge} - SlabThk - StemHaunch - 0.5in$

*The stem must accommodate 1/2" of bituminous fiber.*

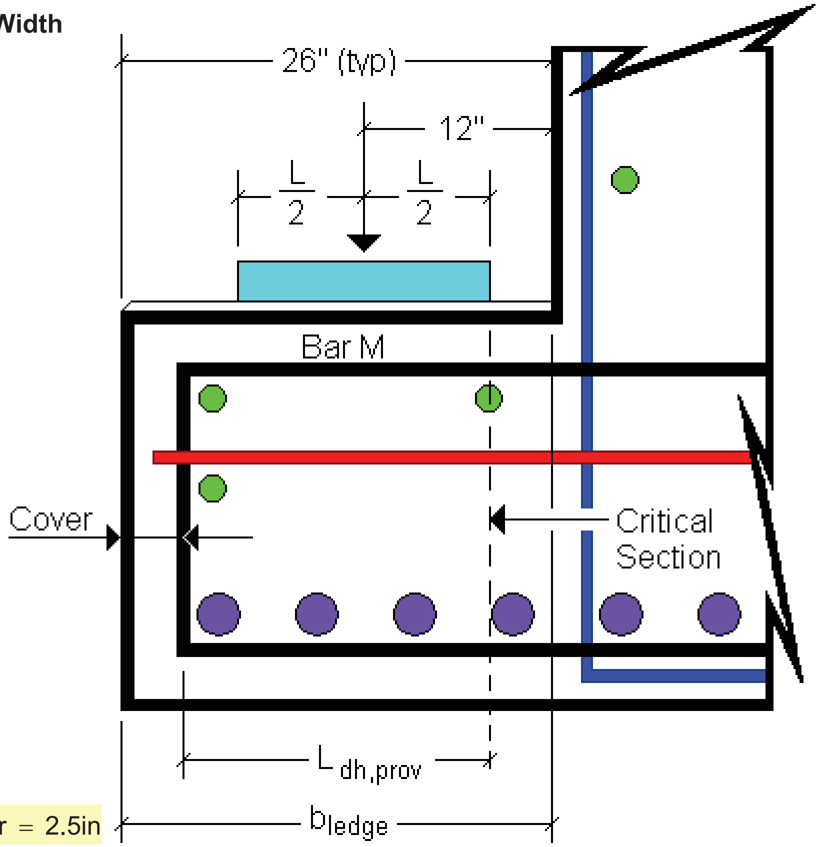
$d_{stem} = 57.75 \cdot in$

Use: $\qquad d_{stem} = 57 \cdot in$

*Round the Stem Height down to the nearest 1". (TxSP)*

## Determine Cap Dimensions (Con't)

**Ledge Width**




*The Ledge Width must be adequate for Bar M to develop fully. 26" is typically used for TX54 girders, as it is adequate to develop a # 6 bar with the typical 2.5" cover. If the cover is increased to 3", allowing for a modification factor of 0.7, a 24" Ledge is adequate to develop a # 7 bar.*

*I-Beams have 9.5" from the face of the cap to the CL of Bearing. The typical ledge width for these bridges is 23".*

*"$L_{dh,prov}$" must be greater than or equal to "$L_{dh,req}$" for bar M.*

$cover = 2.5in$

*"cover" is measured from the center of the transverse bars.*

$L = 8in$

*"L" is the length of the Bearing Pad along the girder. A typical type TX54 bearing pad is 8"x21" as shown in the IGEB standard.*

Determine the Required Development Length of Bar M:

Try # 6 Bar for Bar M.

$d_{bar\_M} = 0.750in$

$A_{bar\_M} = 0.44in^2$

Basic Development Length

$$L_{dh} = \frac{38.0 \cdot d_{bar\_M}}{\sqrt{f'_c}} \qquad L_{dh} = 15.02 \cdot in$$

*(AASHTO LRFD Eq. 5.11.2.4.1-1)*

Modification Factors for $L_{dh}$: *(AASHTO LRFD 5.11.2.4.2)*

Is Top Cover greater than or equal to 2.5", and Side Cover greater than or equal to 2"?

$$SideCover = cover - \frac{d_{bar\_M}}{2} \qquad SideCover = 2.13 \cdot in$$

$$TopCover = cover - \frac{d_{bar\_M}}{2} \qquad TopCover = 2.13 \cdot in$$

*"Side Cover" and "Top Cover" are the clear cover on the side and top of the hook respectively. The dimension "cover" is measured from the center of Bar M.*

No, Factor = 1.0

## Determine Cap Dimensions (Con't)

The Required Development Length is the larger of the following: *(AASHTO LRFD 5.11.2.4.1)*

$L_{dh} \cdot Factor = 15.02 \cdot in$

$8 \cdot d_{bar\_M} = 6.00 \cdot in$

$6in$

Therefore,

$L_{dh\_req} = 15.02 \cdot in$

$b_{ledge\_min} = L_{dh\_req} + cover + 12in - \frac{L}{2}$ $b_{ledge\_min} = 25.52 \cdot in$

*The distance from the face of the stem to the center of bearing is 12" for TxGirders. (IGEB)*

Use:

$b_{ledge} = 26 \cdot in$

**Width of Bottom Flange**

$b_f = 2 \cdot b_{ledge} + b_{stem}$ $b_f = 91 \cdot in$

**Ledge Depth**

Use a Ledge Depth of 28"

$d_{ledge} = 28in$

*As a general rule of thumb Ledge Depth is greater than or equal to 2'-3". This is the depth at which a bent from a typical bridge will pass the punching shear check (calculations found on Pg. 21).*

**Total Depth of Cap**

$h_{cap} = d_{stem} + d_{ledge}$ $h_{cap} = 85 \cdot in$

**Summary of Cross Sectional Dimensions**

$b_{stem} = 39 \cdot in$ *From Pg. 3*

$d_{stem} = 57 \cdot in$ *From Pg. 3*

$b_{ledge} = 26 \cdot in$

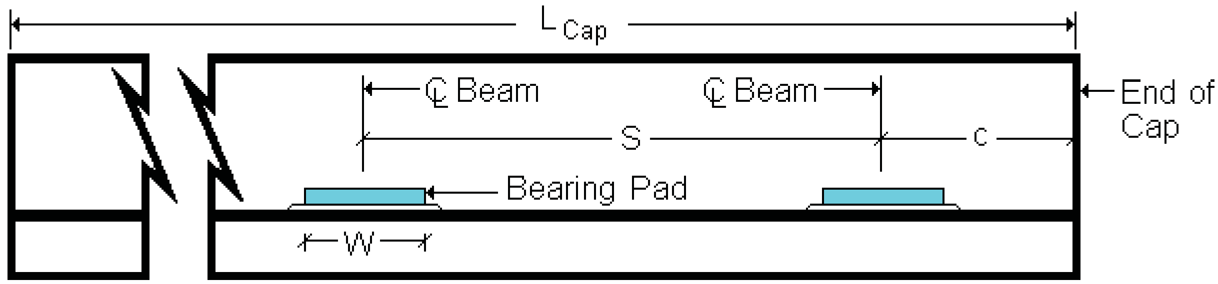
$d_{ledge} = 28 \cdot in$

$h_{cap} = 85 \cdot in$

## Determine Cap Dimensions (Con't)

**Length of Cap**

First define Girder Spacing and End Distance:




**Elevation**

$S = 8ft$ — *Girder Spacing*

$c = 2ft$ — *"c" is the distance from the Center Line of the Exterior Girder to the Edge of the Cap measured along the Cap.*

$L_{Cap} = S \cdot (GdrNo1 - 1) + 2 \cdot c$ $\quad L_{Cap} = 44\,ft$ — *Length of Cap*

*TxDOT policy is as follows, "The edge distance between the exterior bearing pad and the end of the inverted T-beam shall not be less than 12in." (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria) replacing the statement in AASHTO LRFD 5.13.2.5.5 stating it shall not be less than $d_f$. Preferably, the stem should extend at least 3" beyond the edge of the bearing seat.*

**Bearing Pad Dimensions** — *(IGEB standard)*

$L = 8 \cdot in$ — *Length of Bearing Pad*

$W = 21in$ — *Width of Bearing Pad*

## Cross Sectional Properties of Cap

$A_g = d_{ledge} \cdot b_f + d_{stem} \cdot b_{stem}$ $\quad A_g = 4771 \cdot in^2$

$$ybar = \frac{d_{ledge} \cdot b_f \cdot \left(\frac{1}{2} \cdot d_{ledge}\right) + d_{stem} \cdot b_{stem} \cdot \left(d_{ledge} + \frac{1}{2} \cdot d_{stem}\right)}{A_g}$$

*Distance from bottom of cap to the center of gravity of the cap*

$ybar = 33.80 \cdot in$

$$I_g = \frac{b_f \cdot d_{ledge}^{\,3}}{12} + b_f \cdot d_{ledge} \cdot \left(ybar - \frac{1}{2} \cdot d_{ledge}\right)^2 \cdots$$
$$+ \frac{b_{stem} \cdot d_{stem}^{\,3}}{12} + b_{stem} \cdot d_{stem} \cdot \left[ybar - \left(d_{ledge} + \frac{1}{2} \cdot d_{stem}\right)\right]^2$$

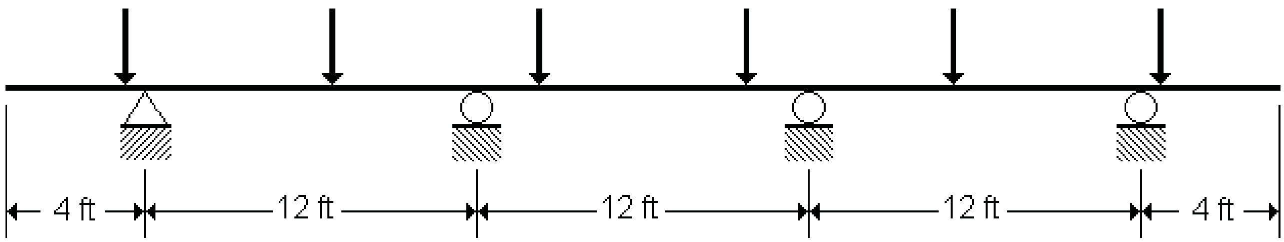
$I_g = 2.91 \times 10^6 \cdot in^4$

## Cap Analysis

### Cap Model

**Assume:**

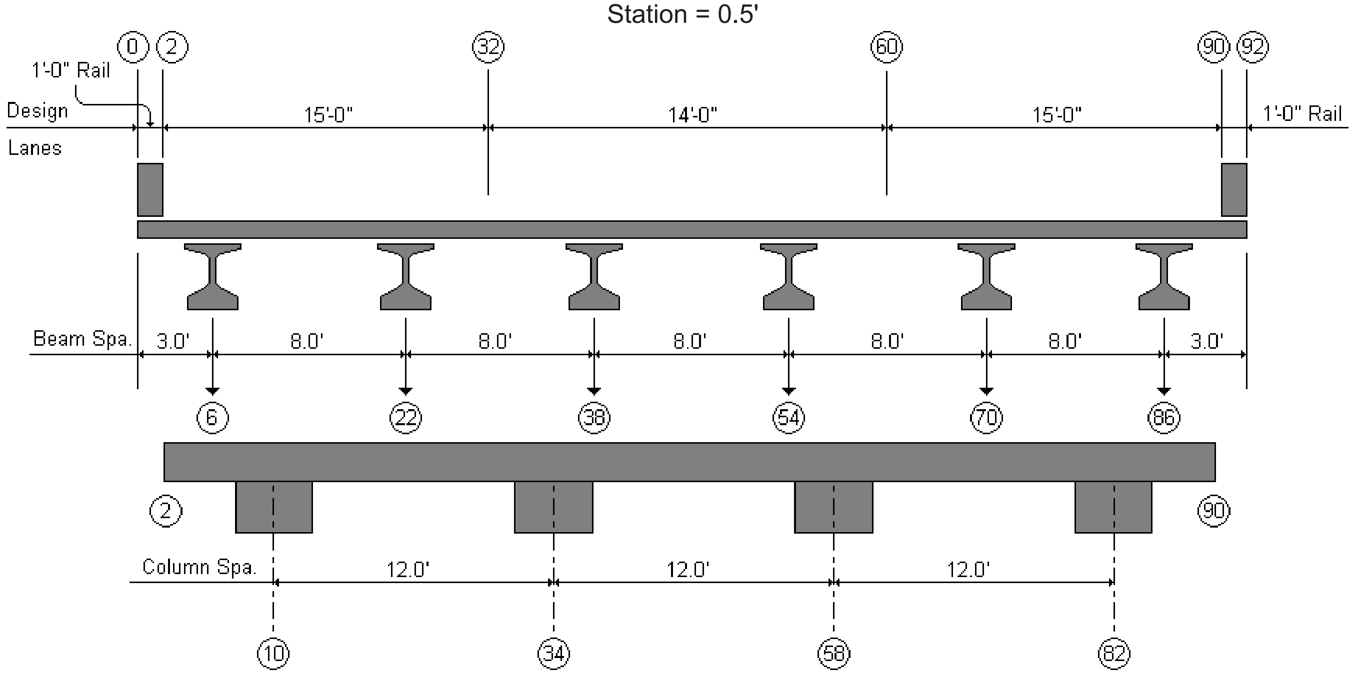
4 Columns Spaced @ 12'-0"
The cap will be modeled as a continuous beam with simple supports using TxDOT's CAP18 program.




TxDOT does not consider frame action for typical multi-column bents.
(*BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis*)

Cap 18 Model

Station = 0.5'




*The circled numbers are the stations that will be used in the CAP 18 input file. One station is 0.5ft in the direction perpendicular to the pgl, not parallel to the bent.*

$station = 0.5ft$ *Station increment for CAP18*

Recall:

$E_c = 3457.14 \cdot ksi$ (Pg. 2) $I_g = 2.91 \times 10^6 \cdot in^4$ (Pg.6)

$$E_c \cdot I_g = 1.01 \times 10^{10} \cdot kip \cdot in^2 \; / \; \left(12 \frac{in}{ft}\right)^2 \quad = \quad E_c \cdot I_g = 6.99 \times 10^7 \cdot kip \cdot ft^2$$

# Cap Analysis (Con't)

## Dead Load

### SPAN 1

*Values used in the following equations can be found on Pg. 2.*

$$Rail1 = \frac{2 \cdot RailWt \cdot \frac{Span1}{2}}{\min(GdrNo1, 6)} \qquad Rail1 = 3.44 \cdot \frac{kip}{girder}$$

*Rail weight is distributed evenly among stringers, up to 3 stringers per rail. (TxSP)*

$$Slab1 = w_c \cdot GdrSpa1 \cdot SlabThk \cdot \frac{Span1}{2} \cdot 1.10 \qquad Slab1 = 23.76 \cdot \frac{kip}{girder}$$

*Increase slab DL by 10% to account for haunch and thickened slab ends.*

$$Girder1 = GdrWt1 \cdot \frac{Span1}{2} \qquad Girder1 = 22.98 \cdot \frac{kip}{girder}$$

$$DLRxn1 = Rail1 + Slab1 + Girder1 \qquad DLRxn1 = 50.17 \cdot \frac{kip}{girder}$$

*Overlay is calculated separately, because it has a different load factor than the rest of the dead loads.*

$$Overlay1 = W_{Olay} \cdot GdrSpa1 \cdot OverlayThk \cdot \frac{Span1}{2} \qquad Overlay1 = 5.04 \cdot \frac{kip}{girder}$$

*Design for future overlay.*

### SPAN 2

$$Rail2 = \frac{2 \cdot RailWt \cdot \frac{Span2}{2}}{\min(GdrNo2, 6)} \qquad Rail2 = 7.13 \cdot \frac{kip}{girder}$$

$$Slab2 = w_c \cdot GdrSpa2 \cdot SlabThk \cdot \frac{Span2}{2} \cdot 1.10 \qquad Slab2 = 49.28 \cdot \frac{kip}{girder}$$

$$Girder2 = GdrWt2 \cdot \frac{Span2}{2} \qquad Girder2 = 47.66 \cdot \frac{kip}{girder}$$

$$DLRxn2 = Rail2 + Slab2 + Girder2 \qquad DLRxn2 = 104.07 \cdot \frac{kip}{girder}$$

$$Overlay2 = W_{Olay} \cdot GdrSpa2 \cdot OverlayThk \cdot \frac{Span2}{2} \qquad Overlay2 = 10.45 \cdot \frac{kip}{girder}$$

### CAP

$$Cap = w_c \cdot A_g = 4.970 \cdot \frac{kip}{ft} \ * \ \frac{0.5ft}{station} \ = \qquad Cap = 2.485 \cdot \frac{kip}{station}$$

## Cap Analysis (Con't)

### Live Load *(AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)*

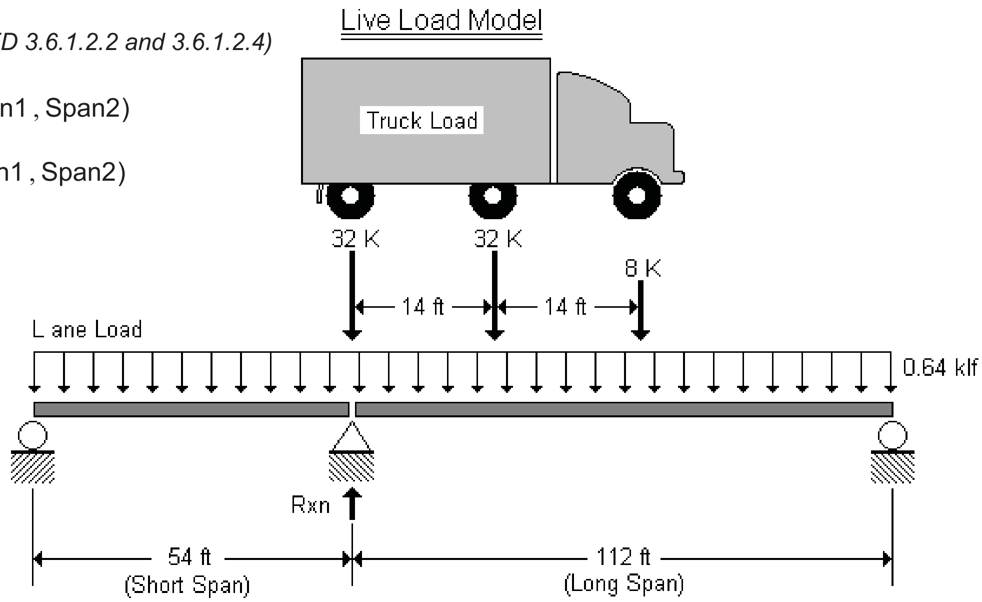
$LongSpan = \max(Span1, Span2)$

$ShortSpan = \min(Span1, Span2)$

$LongSpan = 112.00\,ft$

$ShortSpan = 54.00\,ft$

$IM = 0.33$




$$Lane = 0.64klf \cdot \left(\frac{LongSpan + ShortSpan}{2}\right)$$

$$Lane = 53.12 \cdot \frac{kip}{lane}$$

$$Truck = 32kip + 32kip \cdot \left(\frac{LongSpan - 14ft}{LongSpan}\right) + 8kip \cdot \left(\frac{LongSpan - 28ft}{LongSpan}\right)$$

$$Truck = 66.00 \cdot \frac{kip}{lane}$$

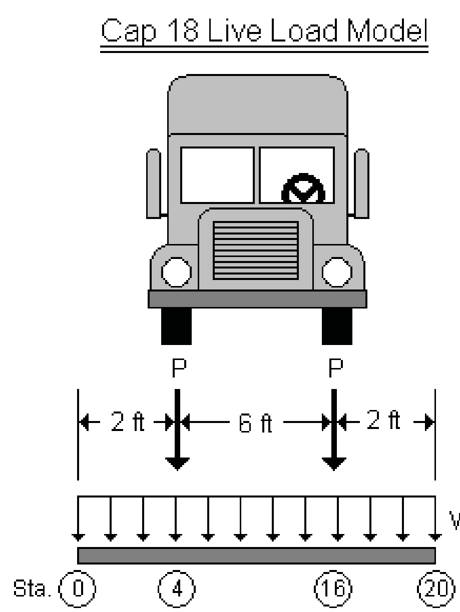
*Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem". For the maximum reaction when the long span is more than twice as long as the short span, place the rear (32 kip) axle over the support and the middle (32 kip) and front (8 kip) axles on the long span. For the maximum reaction when the long span is less than twice as long as the short span, place the middle (32 kip) axle over the support, the front (8 kip) axle on the short span and the rear (32 kip) axle on the long span.*

$$LLRxn = Lane + Truck \cdot (1 + IM)$$

$$LLRxn = 140.90 \cdot \frac{kip}{lane}$$

*Combine "Design Truck" and "Design Lane" loadings. (AASHTO LRFD 3.6.1.3)*

*Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)*




$$P = 16.0kip \cdot (1 + IM)$$

$$P = 21.28 \cdot kip$$

*The Live Load is applied to the slab by two 16 kip wheel loads increased by the dynamic load allowance with the remainder of the live load distributed over a 10 ft (AASHTO LRFD 3.6.1.2.1) design lane width. (TxSP)*

$$w = \frac{LLRxn - (2 \cdot P)}{10ft}$$

$$w = 9.83 \cdot \frac{kip}{ft} * \frac{0.5ft}{station}$$

$$w = 4.92 \cdot \frac{kip}{station}$$

*The Live Load applied to the slab is distributed to the beams assuming the slab is hinged at each beam except the outside beam. (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis)*

## Cap Analysis (Con't)

### Cap 18 Input

Multiple Presence Factors, m *(AASHTO LRFD Table 3.6.1.1.2-1)*

*Input "Multiple Presence Factors" into Cap18 as "Load Reduction Factors".*

| No. of Lanes | Factor "m" |
|---|---|
| 1 | 1.20 |
| 2 | 1.00 |
| 3 | 0.85 |
| >3 | 0.65 |

### Limit States *(AASHTO LRFD 3.4.1)*

*The cap design need only consider Strength I, Service I, and Service I with DL. (TxSP)*

Strength I

Live Load and Dynamic Load Allowance LL + IM = 1.75

Dead Load Components DC = 1.25

Dead Load Wearing Surface (Overlay) DW = 1.50

*TxDOT allows the Overlay Factor to be reduced to 1.25 (TxSP), since overlay is typically used in design only to increase the safety factor, but in this example we will use DW = 1.50.*

Service I

Live Load and Dynamic Load Allowance LL + IM = 1.00

Dead Load and Wearing Surface DC & DW = 1.00

Dead Load

TxDOT considers Service level Dead Load only with a limit reinforcement stress of 22 ksi to minimize cracking.
*(BDM-LRFD, Chapter 4, Section 5, Design Criteria)*

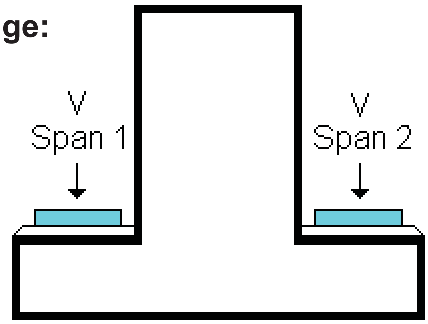
### Cap 18 Output

| | Max +M | Max -M |
|---|---|---|
| Dead Load: | $M_{posDL} = 250.1 kip \cdot ft$ | $M_{negDL} = -379.4 kip \cdot ft$ |
| Service Load: | $M_{posServ} = 492.5 kip \cdot ft$ | $M_{negServ} = -590.9 kip \cdot ft$ |
| Factored Load: | $M_{posUlt} = 741.7 kip \cdot ft$ | $M_{negUlt} = -852.1 kip \cdot ft$ |

*These loads are the maximum loads from the Cap 18 Output File located in the Appendices.*

## Cap Analysis (Con't)

### Girder Reactions on Ledge:




### Dead Load

$DLSpan1 = Rail1 + Slab1 + Girder1$ $\quad DLSpan1 = 50.17 \cdot \frac{kip}{girder}$ *For calculations of these loads* *see Pg. 8.*

$Overlay1 = 5.04 \cdot \frac{kip}{girder}$

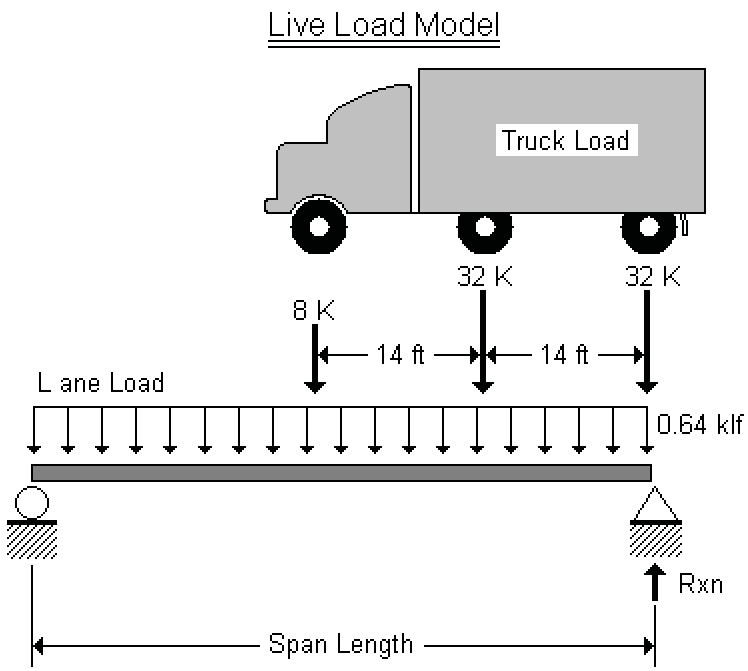
$DLSpan2 = Rail2 + Slab2 + Girder2$ $\quad DLSpan2 = 104.07 \cdot \frac{kip}{girder}$

$Overlay2 = 10.45 \cdot \frac{kip}{girder}$

### Live Load *(AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)*

Loads per Lane:

*Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem" for Spans greater than 26ft. For the maximum reaction, place the back (32 kip) axle over the support.*




$LaneSpan1 = 0.64klf \cdot \left(\frac{Span1}{2}\right)$ $\quad LaneSpan1 = 17.28 \cdot \frac{kip}{lane}$

$LaneSpan2 = 0.64klf \cdot \left(\frac{Span2}{2}\right)$ $\quad LaneSpan2 = 35.84 \cdot \frac{kip}{lane}$

$TruckSpan1 = 32.0kip + 32.0kip \cdot \left(\frac{Span1 - 14ft}{Span1}\right) + 8.0kip \cdot \left(\frac{Span1 - 28ft}{Span1}\right)$ $\quad TruckSpan1 = 59.56 \cdot \frac{kip}{lane}$

$TruckSpan2 = 32.0kip + 32.0kip \cdot \left(\frac{Span2 - 14ft}{Span2}\right) + 8.0kip \cdot \left(\frac{Span2 - 28ft}{Span2}\right)$ $\quad TruckSpan2 = 66.00 \cdot \frac{kip}{lane}$

## Cap Analysis (Con't)

### Girder Reactions on Ledge (Con't) :

Live Load **(Con't)**

Loads per Lane (Con't) :

$IM = 0.33$

*Combine "Design Truck" and "Design Lane" loadings. (AASHTO LRFD 3.6.1.3)*

*Dynamic load allowance, "IM", does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)*

$LLRxnSpan1 = LaneSpan1 + TruckSpan1 \cdot (1 + IM)$

$LLRxnSpan1 = 96.49 \cdot \frac{kip}{lane}$

$LLRxnSpan2 = LaneSpan2 + TruckSpan2 \cdot (1 + IM)$

$LLRxnSpan2 = 123.62 \cdot \frac{kip}{lane}$

$gV_{Span1\_Int} = 0.814$

$gV_{Span1\_Ext} = 0.814$

$gV_{Span2\_Int} = 0.814$

$gV_{Span2\_Ext} = 0.814$

*The Live Load Reactions are assumed to be the Shear Live Load Distribution Factor multiplied by the Live Load Reaction per Lane. The Shear Live Load Distribution Factor was calculated using the "LRFD Live Load Distribution Factors" Spreadsheet found in the Appendices.*

*The Exterior Girders must have a Live Load Distribution Factor equal to or greater than the Interior Girders. This is to accommodate a possible future bridge widening. Widening the bridge would cause the exterior girders to become interior girders.*

$LLSpan1Int = gV_{Span1\_Int} \cdot LLRxnSpan1$ $\quad LLSpan1Int = 78.54 \cdot \frac{kip}{girder}$

$LLSpan1Ext = gV_{Span1\_Ext} \cdot LLRxnSpan1$ $\quad LLSpan1Ext = 78.54 \cdot \frac{kip}{girder}$

$LLSpan2Int = gV_{Span2\_Int} \cdot LLRxnSpan2$ $\quad LLSpan2Int = 100.63 \cdot \frac{kip}{girder}$

$LLSpan2Ext = gV_{Span2\_Ext} \cdot LLRxnSpan2$ $\quad LLSpan2Ext = 100.63 \cdot \frac{kip}{girder}$

## Cap Analysis (Con't)

### Girder Reactions on Ledge (Con't) :

Span 1

Interior Girder

Service Load *Service I Limit State, (AASHTO LRFD 3.4.1)*

$V_{s\_Span1Int} = DLSpan1 + Overlay1 + LLSpan1Int$ $V_{s\_Span1Int} = 134 \cdot kip$

Factored Load *Strength I Limit State, (AASHTO LRFD 3.4.1)*

$V_{u\_Span1Int} = 1.25DLSpan1 + 1.5 \cdot Overlay1 + 1.75LLSpan1Int$ $V_{u\_Span1Int} = 208 \cdot kip$

Exterior Girder

Service Load *Service I Limit State, (AASHTO LRFD 3.4.1)*

$V_{s\_Span1Ext} = DLSpan1 + Overlay1 + LLSpan1Ext$ $V_{s\_Span1Ext} = 134 \cdot kip$

Factored Load *Strength I Limit State, (AASHTO LRFD 3.4.1)*

$V_{u\_Span1Ext} = 1.25DLSpan1 + 1.5 \cdot Overlay1 + 1.75LLSpan1Ext$ $V_{u\_Span1Ext} = 208 \cdot kip$

Span 2

Interior Girder

Service Load *Service I Limit State, (AASHTO LRFD 3.4.1)*

$V_{s\_Span2Int} = DLSpan2 + Overlay2 + LLSpan2Int$ $V_{s\_Span2Int} = 215 \cdot kip$

Factored Load *Strength I Limit State, (AASHTO LRFD 3.4.1)*

$V_{u\_Span2Int} = 1.25DLSpan2 + 1.5 \cdot Overlay2 + 1.75LLSpan2Int$ $V_{u\_Span2Int} = 322 \cdot kip$

Exterior Girder

Service Load *Service I Limit State, (AASHTO LRFD 3.4.1)*

$V_{s\_Span2Ext} = DLSpan2 + Overlay2 + LLSpan2Ext$ $V_{s\_Span2Ext} = 215 \cdot kip$

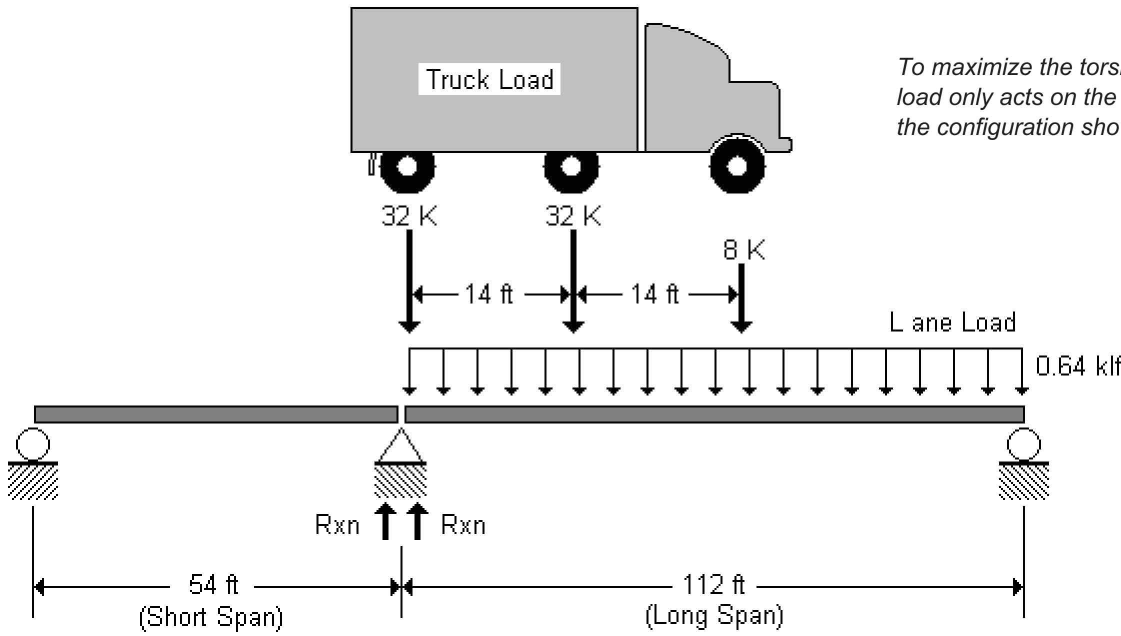
Factored Load *Strength I Limit State, (AASHTO LRFD 3.4.1)*

$V_{u\_Span2Ext} = 1.25DLSpan2 + 1.5 \cdot Overlay2 + 1.75LLSpan2Ext$ $V_{u\_Span2Ext} = 322 \cdot kip$

## Cap Analysis (Con't)

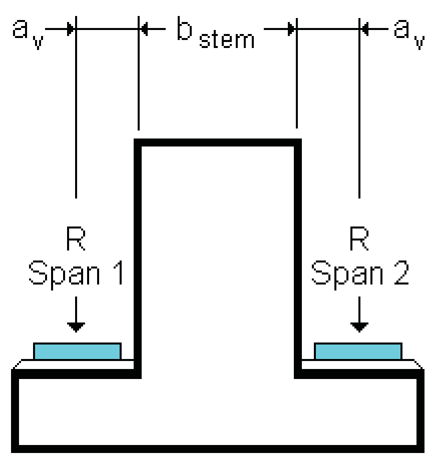
### Torsional Loads

*Strength I Limit State, (AASHTO LRFD 3.4.1)*




*To maximize the torsion, the live load only acts on the longer span in the configuration shown.*

The loads are applied to the cap as depicted in the following picture:




$a_v = 12in$

*"$a_v$" is the value for the distance from the face of the stem to the center of bearing for the girders. 12" is the typical value for TxGirders on Inverted Tee Bents (IGEB). 9" is the typical value for I-Beams (IBEB). The lever arm for the torsional loads is the distance from the center line of bearing to the centerline of the cap ($\frac{1}{2}b_{stem} + a_v$).*

$b_{stem} = 39 \cdot in$ *From Pg. 3*

$LeverArm = a_v + \frac{1}{2} \cdot b_{stem}$ $LeverArm = 31.5 \cdot in$

## Cap Analysis (Con't)

### Torsional Loads (Con't)

#### Interior Girders

Girder Reactions

$R_{u\_Span1} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$ $\quad R_{u\_Span1} = 70 \cdot kip$

$R_{u\_Span2} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2\_Int} \cdot [LaneSpan2 + TruckSpan2 \cdot (1 + IM)]$

$R_{u\_Span2} = 322 \cdot kip$

Torsional Load

$T_{u\_Int} = \left| R_{u\_Span1} - R_{u\_Span2} \right| \cdot LeverArm$ $\quad T_{u\_Int} = 660 \cdot kip \cdot ft$

#### Exterior Girders

Girder Reactions

$R_{u\_Span1} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$ $\quad R_{u\_Span1} = 70 \cdot kip$

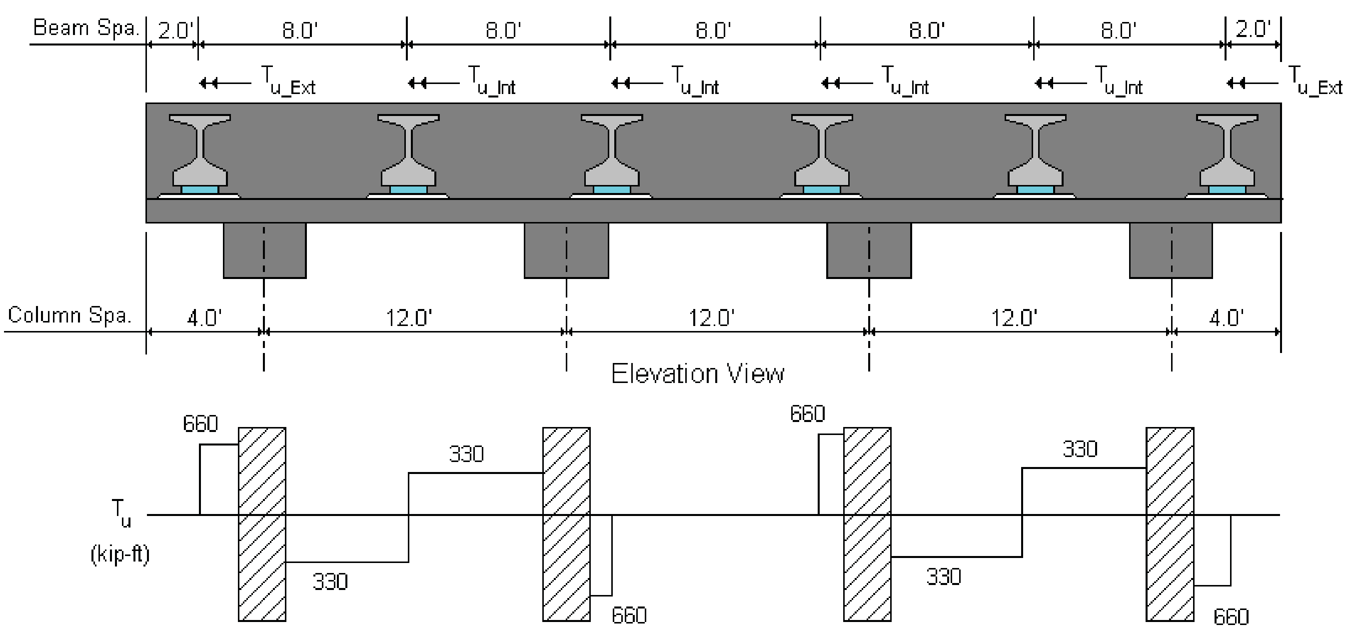
$R_{u\_Span2} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2\_Ext} \cdot [LaneSpan2 + TruckSpan2 \cdot (1 + IM)]$

$R_{u\_Span2} = 322 \cdot kip$

Torsional Load

$T_{u\_Ext} = \left| R_{u\_Span1} - R_{u\_Span2} \right| \cdot LeverArm$ $\quad T_{u\_Ext} = 660 \cdot kip \cdot ft$

### Torsion on Cap




Analyzed assuming Bents are torsionally rigid at Effective Face of Columns.

$T_u = 660 kip \cdot ft$ *Maximum Torsion on Cap*

## Cap Analysis (Con't)

### Load Summary

#### Ledge Loads

Interior Girder

Service Load

$V_{s\_Int} = \max\left(V_{s\_Span1Int}, V_{s\_Span2Int}\right)$ $V_{s\_Int} = 215.15 \cdot kip$

Factored Load

$V_{u\_Int} = \max\left(V_{u\_Span1Int}, V_{u\_Span2Int}\right)$ $V_{u\_Int} = 321.86 \cdot kip$

Exterior Girder

Service Load

$V_{s\_Ext} = \max\left(V_{s\_Span1Ext}, V_{s\_Span2Ext}\right)$ $V_{s\_Ext} = 215.15 \cdot kip$

Factored Load

$V_{u\_Ext} = \max\left(V_{u\_Span1Ext}, V_{u\_Span2Ext}\right)$ $V_{u\_Ext} = 321.86 \cdot kip$

#### Cap Loads

Positive Moment (From CAP 18)

Dead Load: $M_{posDL} = 250.10 \cdot kip \cdot ft$

Service Load: $M_{posServ} = 492.50 \cdot kip \cdot ft$

Factored Load: $M_{posUlt} = 741.70 \cdot kip \cdot ft$

Negative Moment (From CAP 18)

Dead Load: $M_{negDL} = -379.40 \cdot kip \cdot ft$

Service Load: $M_{negServ} = -590.90 \cdot kip \cdot ft$

Factored Load: $M_{negUlt} = -852.10 \cdot kip \cdot ft$

Maximum Torsion and Concurrent Shear and Moment (Strength I)

$T_u = 660 \cdot kip \cdot ft$

$V_u = 448.1 kip$

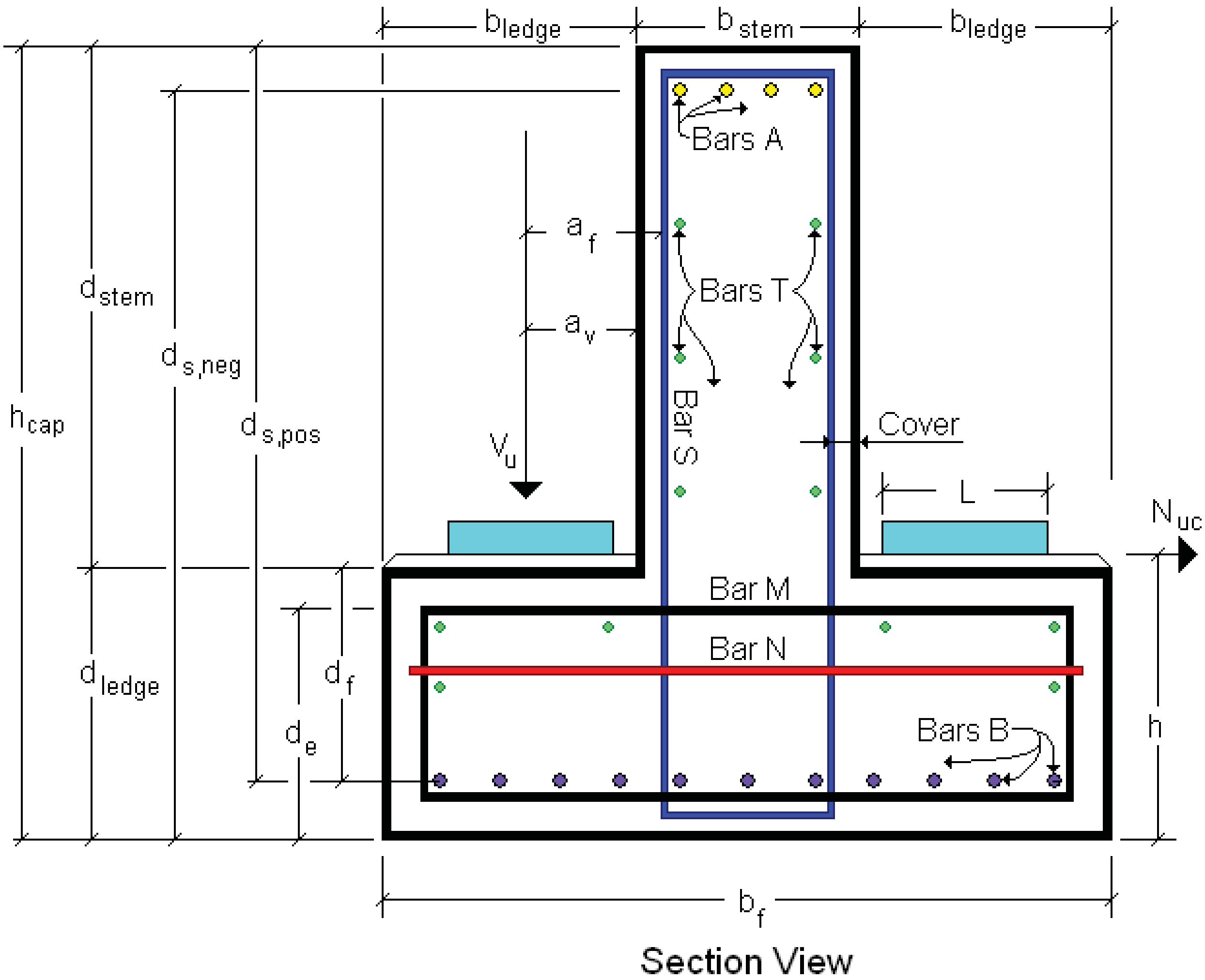
$M_u = 335.6 kip \cdot ft$

*Located two stations away from centerline of column.*

$V_u$ and $M_u$ values are from CAP 18

*In this example the maximum Torsion and the maximum Shear are concurrent with each other. If they are not, it becomes necessary to check the location of the maximum Torsion with its concurrent Shear and the location of the maximum Shear with its concurrent Torsion.*

## Locate and Describe Reinforcement




Section View

Recall:

$b_{stem} = 39 \cdot in$ *From Pg. 3*

$d_{stem} = 57 \cdot in$ *From Pg. 3*

$b_{ledge} = 26 \cdot in$ *From Pg. 5*

$d_{ledge} = 28 \cdot in$ *From Pg. 5*

$b_f = 91 \cdot in$ *From Pg. 5*

$h_{cap} = 85 \cdot in$ *From Pg. 5*

$cover = 2.50 \cdot in$ *From Pg. 4*
*Measured from Center of bar*

## Locate and Describe Reinforcement (Con't)

### Describe Reinforcing Bars

Use # 11 bars for Bar A

$A_{bar\_A} = 1.56in^2$ $d_{bar\_A} = 1.410in$

Use # 11 bars for Bar B

$A_{bar\_B} = 1.56in^2$ $d_{bar\_B} = 1.410in$

Use # 6 bars for Bar M

$A_{bar\_M} = 0.44in^2$ $d_{bar\_M} = 0.75in$

*Bar M must be a # 6 bar or smaller to allow it to fully develop, as stated on Pg 4.*

Use # 6 bars for Bar N

$A_{bar\_N} = 0.44in^2$ $d_{bar\_N} = 0.75in$

*To prevent confusion, use the same bar size for Bar N as Bar M.*

Use # 6 bars for Bar S

$A_{bar\_S} = 0.44in^2$ $d_{bar\_S} = 0.75in$

Use # 6 bars for Bar T

$A_{bar\_T} = 0.44in^2$ $d_{bar\_T} = 0.750in$

### Calculate Dimensions

$$d_{s\_neg} = h_{cap} - cover - \frac{1}{2} \cdot d_{bar\_S} - \frac{1}{2} \cdot d_{bar\_A}$$

$$d_{s\_neg} = 81.42 \cdot in$$

$$d_{s\_pos} = h_{cap} - cover - \frac{1}{2} \cdot max\left(d_{bar\_S}, d_{bar\_M}\right) - \frac{1}{2} \cdot d_{bar\_B}$$

$$d_{s\_pos} = 81.42 \cdot in$$

$a_v = 12 \cdot in$

*Typical for TX Girders on Inverted Tee Bent Caps (IGEB standard)*

$a_f = a_v + cover$ $a_f = 14.50 \cdot in$

$d_e = d_{ledge} - cover$ $d_e = 25.50 \cdot in$

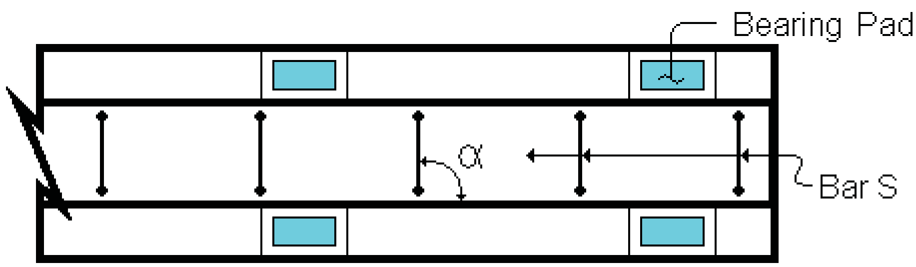
$d_f = d_{ledge} - cover - \frac{1}{2} \cdot d_{bar\_M} - \frac{1}{2} \cdot d_{bar\_B}$ $d_f = 24.42 \cdot in$

$h = d_{ledge} + BrgSeat$ $h = 29.50 \cdot in$

*"BrgSeat" is the height of the Bearing Seat Buildup. This value is defined on Pg. 2.*

## Locate and Describe Reinforcement (Con't)

### Calculate Dimensions (Con't)




Plan View

$\alpha = 90\text{deg}$ *Angle of Bars S*

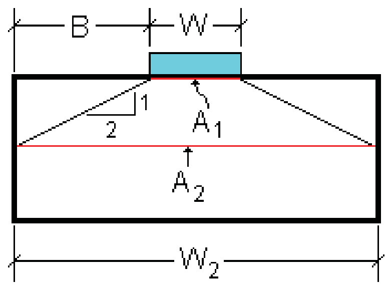
Recall:

$L = 8 \cdot \text{in}$ *From Pg. 4*

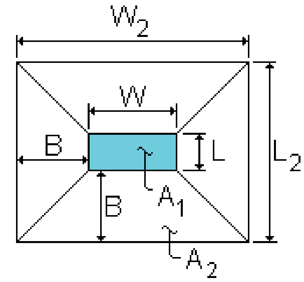
$W = 21 \cdot \text{in}$ *From Pg. 6*

## Check Bearing *(AASHTO LRFD 5.7.5)*

The load on the bearing pad propagates along a truncated pyramid whose top has the area $A_1$ and whose base has the area $A_2$. $A_1$ is the loaded area (the bearing pad area: LxW ). $A_2$ is the area of the lowest rectangle contained wholly within the support (the Inverted Tee Cap). $A_2$ must not overlap the truncated pyramid of another load in either direction, nor can it extend beyond the edges of the cap in any direction.



Elevation View



Plan View

$\phi = 0.7$ *(AASHTO LRFD 5.5.4.2.1)*

$A_1 = W \cdot L$ $\quad A_1 = 168 \cdot in^2$ *Area under Bearing Pad*

### Interior Girders

$$B = \min\left[\left(b_{ledge} - a_v\right) - \frac{1}{2} \cdot L, \left(a_v + \frac{1}{2} \cdot b_{stem}\right) - \frac{1}{2} \cdot L, 2d_{ledge}, \frac{1}{2} \cdot S - \frac{1}{2} \cdot W\right]$$

*"B" is the distance from the perimeter of $A_1$ to the perimeter of $A_2$, as seen in the above figures.*

$B = 10.00 \cdot in$

$L_2 = L + 2 \cdot B$ $\quad L_2 = 28.00 \cdot in$

$W_2 = W + 2 \cdot B$ $\quad W_2 = 41.00 \cdot in$

$A_2 = L_2 \cdot W_2$ $\quad A_2 = 1148 \cdot in^2$

m = the minimum of: *Modification Factor*

$\sqrt{\frac{A_2}{A_1}} = 2.61$ & 2 $\quad m = 2.00$ *(AASHTO LRFD Eq. 5.7.5-3)*

$\phi V_n = \phi \cdot 0.85 \cdot f_c \cdot A_1 \cdot m$ $\quad \phi V_n = 720 \cdot kip$ *(AASHTO LRFD Eq. 5.7.5-1 & AASHTO LRFD Eq. 5.7.5-2)*

$V_{u\_Int} = 322 \cdot kip \quad < \quad \phi V_n$ $\quad$ BearingChk = "OK!" $\quad$ *$V_{u\_Int}$ From Pg. 16*

### Exterior Girders

$$B = \min\left[\left(b_{ledge} - a_v\right) - \frac{1}{2} \cdot L, \left(a_v + \frac{1}{2} \cdot b_{stem}\right) - \frac{1}{2} \cdot L, 2d_{ledge}, \frac{1}{2} \cdot S - \frac{1}{2} \cdot W, c - \frac{1}{2} \cdot W\right]$$

$B = 10.00 \cdot in$

*"B" is the distance from the perimeter of $A_1$ to the perimeter of $A_2$.*

$L_2 = L + 2 \cdot B$ $\quad L_2 = 28.00 \cdot in$

$W_2 = W + 2 \cdot B$ $\quad W_2 = 41.00 \cdot in$

$A_2 = L_2 \cdot W_2$ $\quad A_2 = 1148 \cdot in^2$

m = the minimum of: *Modification Factor*

$\sqrt{\frac{A_2}{A_1}} = 2.61$ & 2 $\quad m = 2.00$ *(AASHTO LRFD Eq. 5.7.5-3)*

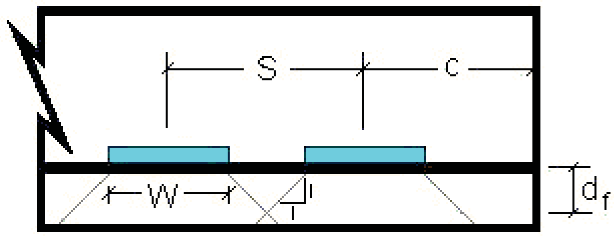
$\phi V_n = \phi \cdot 0.85 \cdot f_c \cdot A_1 \cdot m$ $\quad \phi V_n = 720 \cdot kip$ *(AASHTO LRFD Eq. 5.7.5-1 & AASHTO LRFD Eq. 5.7.5-2)*

$V_{u\_Ext} = 322 \cdot kip \quad < \quad \phi V_n$ $\quad$ BearingChk = "OK!" $\quad$ *$V_{u\_Ext}$ From Pg. 16*

## Check Punching Shear

*(AASHTO LRFD 5.13.2.5.4 with modifications from BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$\phi = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*




Elevation

### Determine if the Shear Cones Intersect

Is $\frac{1}{2}\cdot S - \frac{1}{2}\cdot W \geq d_f$ ? Yes. Therefore Shear Cones do not intersect in the longitudinal direction of the Cap.

$$\frac{1}{2}\cdot S - \frac{1}{2}\cdot W = 37.50\cdot in$$

$$d_f = 24.42\cdot in$$

*TxDOT uses "$d_f$" instead of "$d_e$" for Punching Shear (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria). This is because "$d_f$" has traditionally been used for inverted tee bents and was used in the Inverted Tee Research (Furlong & Mirza pg. 58).*

Is $\frac{1}{2}b_{stem} + a_v - \frac{1}{2}\cdot L \geq d_f$ ? Yes. Therefore Shear Cones do not intersect in the transverse direction of the Cap.

$$\frac{1}{2}b_{stem} + a_v - \frac{1}{2}\cdot L = 27.50\cdot in$$

$$d_f = 24.42\cdot in$$

### Interior Girders

$$V_n = 0.125\cdot\sqrt{f_c}\cdot\left(W + 2\cdot L + 2\cdot d_f\right)\cdot d_f \qquad V_n = 497\cdot kip$$

*(BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$$\phi V_n = 447\cdot kip$$

$V_{u\_Int} = 322\cdot kip < \phi V_n$ PunchingShearChk = "OK!" *$V_{u\_Int}$ From Pg. 16*

### Exterior Girders

$V_n$ = minimum of: *(BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$$0.125\cdot\sqrt{f_c}\cdot\left(\frac{1}{2}\cdot W + L + d_f + c\right)\cdot d_f = 388\cdot kip$$

$$0.125\cdot\sqrt{f_c}\cdot\left(W + 2\cdot L + 2d_f\right)\cdot d_f = 497\cdot kip$$

$$V_n = 388\cdot kip$$

$$\phi V_n = 349\cdot kip$$

$V_{u\_Ext} = 322\cdot kip < \phi V_n$ PunchingShearChk = "OK!" *$V_{u\_Ext}$ From Pg. 16*

## Check Shear Friction *(AASHTO LRFD 5.13.2.5.2)*

*Checks are for concrete only see "Ledge Reinforcement" for reinforcement checks for Bars M and N.*

$\phi = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

### Determine the Distribution Width *(AASHTO LRFD 5.13.2.5.2)*

Interior Girders

$b_{s\_Int}$ = minimum of:

$W + 4\ a_v = 69.00 \cdot in$

$S = 96.00 \cdot in$ *"S" is the girder spacing.*

$b_{s\_Int} = 69.00 \cdot in$

Exterior Girders

$b_{s\_Ext}$ = minimum of:

$W + 4\ a_v = 69.00 \cdot in$

$S = 96.00 \cdot in$ *"S" is the girder spacing.*

$2\ c = 48.00 \cdot in$

$b_{s\_Ext} = 48.00 \cdot in$

### Interior Girders

$A_{cv} = d_e \cdot b_{s\_Int}$ $A_{cv} = 1759 \cdot in^2$

$V_n$ = minimum of:

$0.2\ f_c \cdot A_{cv} = 1267 \cdot kip$ *(AASHTO LRFD Eq. 5.13.2.4.2-1)*

$0.8\ ksi \cdot A_{cv} = 1408 \cdot kip$ *(AASHTO LRFD Eq. 5.13.2.4.2-2)*

$V_n = 1267 \cdot kip$

$\phi V_n = 1140 \cdot kip$

$V_{u\_Int} = 322 \cdot kip$ < $\phi V_n$ ShearFrictionChk = "OK!" *$V_{u\_Int}$ From Pg. 16*

### Exterior Girders

$A_{cv} = d_e \cdot b_{s\_Ext}$ $A_{cv} = 1224 \cdot in^2$

$V_n$ = minimum of:

$0.2\ f_c \cdot A_{cv} = 881 \cdot kip$ *(AASHTO LRFD Eq. 5.13.2.4.2-1)*

$0.8\ ksi \cdot A_{cv} = 979 \cdot kip$ *(AASHTO LRFD Eq. 5.13.2.4.2-2)*

$V_n = 881 \cdot kip$

$\phi V_n = 793 \cdot kip$

$V_{u\_Ext} = 322 \cdot kip$ < $\phi V_n$ ShearFrictionChk = "OK!" *$V_{u\_Ext}$ From Pg. 16*

## Flexural Reinforcement for Negative Bending (Bars A)

(Tension in Top)

$M_{dl} = |M_{negDL}|$ $M_{dl} = 379.4 \cdot kip \cdot ft$

$M_s = |M_{negServ}|$ $M_s = 590.9 \cdot kip \cdot ft$ *From Cap 18 Output. See Pg. 10*

$M_u = |M_{negUlt}|$ $M_u = 852.1 \cdot kip \cdot ft$

### Minimum Flexural Reinforcement *(AASHTO LRFD 5.7.3.3.2)*

Factored Flexural Resistance, $M_r$, must be <u>greater</u> than or equal to the lesser of 1.2 $M_{cr}$ (Cracking Moment) or 1.33 Mu (Ultimate Moment)

$I_g = 2.91 \times 10^6 \cdot in^4$ *Gross Moment of Inertia (From Pg. 6)*

$h_{cap} = 85 \cdot in$ *Depth of Cap (From Pg. 5)*

$ybar = 33.80 \cdot in$ *Distance to the Center of Gravity of the Cap from the bottom of the Cap (From Pg. 6)*

$f_r = 0.24 \cdot \sqrt{f_c}$ $f_r = 0.455 \cdot ksi$ *Modulus of Rupture (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$y_t = h_{cap} - ybar$ $y_t = 51.20 \cdot in$ *Distance from Center of Gravity to extreme tension fiber*

$S = \frac{I_g}{y_t}$ $S = 5.69 \times 10^4 \cdot in^3$ *Section Modulus for the extreme tension fiber*

$M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ $M_{cr} = 2158.9 \cdot kip \cdot ft$ *Cracking Moment (AASHTO LRFD Eq. 5.7.3.3.2-1)*

$M_f$ = minimum of:

$1.2 \cdot M_{cr} = 2590.7 \cdot kip \cdot ft$

$1.33 \cdot M_u = 1133.3 \cdot kip \cdot ft$

*Design for the <u>lesser</u> of 1.2$M_{cr}$ or 1.33Mu when determining minimum area of steel required.*

Thus, $M_r$ must be <u>greater</u> than $M_f = 1133.3 \cdot kip \cdot ft$

## Flexural Reinforcement for Negative Bending (Con't) (Bars A)

### Moment Capacity Design *(AASHTO LRFD 5.7.3.2)*

Try, 5 ~ #11's Top

| | | |
|---|---|---|
| $BarANo = 5$ | | *Number of bars in tension* |
| $d_{bar\_A} = 1.41in$ | | *Diameter of main reinforcing bars* |
| $A_{bar\_A} = 1.56in^2$ | | *Area of one main reinforcing bar* |
| $A_s = (BarANo) \cdot A_{bar\_A}$ | $A_s = 7.80 \cdot in^2$ | *Area of steel in tension* |
| $d_{stirrup} = d_{bar\_S}$ | $d_{stirrup} = 0.75 \cdot in$ | *Diameter of shear reinforcing bars From Pg. 18* |
| $d = d_{s\_neg}$ | $d = 81.42 \cdot in$ | *See Pg. 18 for the calculation of "$d_{s\_neg,}$"* |
| $b = b_f$ | $b = 91 \cdot in$ | *See Pg. 5 for the calculation of "$b_f$"* |
| $f_c = 3.60 \cdot ksi$ | | *Compressive Strength of Concrete* |
| $f_y = 60ksi$ | | *Yield Strength of Rebar* |
| $\beta_1 = 0.85 - 0.05 \cdot (f_c - 4ksi)$ | | *(AASHTO LRFD 5.7.2.2)* |
| Bounded by: $0.65 \le \beta_1 \le 0.85$ | $\beta_1 = 0.85$ | |
| $c = \dfrac{A_s \cdot f_y}{0.85 \cdot f_c \cdot \beta_1 \cdot b}$ | $c = 1.98 \cdot in$ | *Depth of Cross Section under Compression under Ultimate Load (AASHTO LRFD Eq. 5.7.3.1.2-4)* |

*This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.*

| | | |
|---|---|---|
| $a = c \cdot \beta_1$ | $a = 1.68 \cdot in$ | *Depth of Equivalent Stress Block (AASHTO LRFD 5.7.2.2)* |

*Note: "a" is less than "$d_{ledge}$" therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "$d_{ledge}$" it would act over a Tee shaped area.*

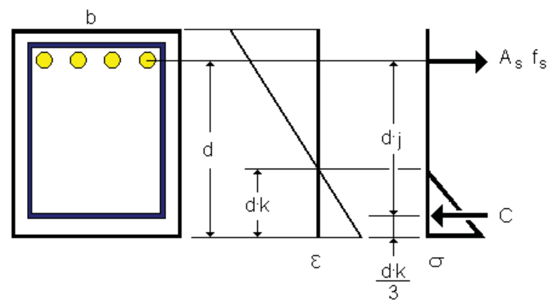
| | | |
|---|---|---|
| $M_n = A_s \cdot f_y \cdot \left(d - \dfrac{a}{2}\right) \cdot \dfrac{1ft}{12in}$ | $M_n = 3142.6 \cdot kip \cdot ft$ | *Nominal Flexural Resistance (AASHTO LRFD Eq. 5.7.3.2.2-1)* |
| $\varepsilon_s = 0.003 \cdot \dfrac{d - c}{c}$ | $\varepsilon_s = 0.121$ | *Strain in Reinforcing at Ultimate* |
| $\varepsilon_s > 0.005$ | | |
| FlexureBehavior = "Tension Controlled" | | *(AASHTO LRFD 5.7.2.1)* |
| $\phi_M = 0.90$ | | *(AASHTO LRFD 5.5.4.2.1)* |
| $M_r = \phi_M \cdot M_n$ | $M_r = 2828.3 \cdot kip \cdot ft$ | *Factored Flexural Resistance (AASHTO LRFD Eq. 5.7.3.2.1-1)* |
| $M_f = 1133.3 \cdot kip \cdot ft < M_r$ | MinReinfChk = "OK!" | |
| $M_u = 852.1 \cdot kip \cdot ft < M_r$ | UltimateMom = "OK!" | |

## Flexural Reinforcement for Negative Bending (Con't) (Bars A)

### Check Serviceability *(AASHTO LRFD 5.7.3.4)*

To find $s_{max}$ :

*For service loads, the stress on the cross-section is located as drawn:*




Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad n = 8.39$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \rho = 0.0011$$

$$k = \sqrt{(2 \cdot \rho \cdot n) + (\rho \cdot n)^2} - (\rho \cdot n) \qquad k = 0.124$$

$d \cdot k = 10.13 \cdot in \quad < \quad d_{ledge} = 28.00 \cdot in$ Therefore, the compression force acts over a rectangular area.

$$j = 1 - \frac{k}{3} \qquad j = 0.959$$

*If the compression force does not act over a rectangular area, j will not be 1-k/3.*

$$f_{ss} = \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12in}{1ft} \qquad f_{ss} = 11.65 \cdot ksi$$

*Service Load Bending Stress in outer layer of the reinforcing*

$$f_a = 0.6 \cdot f_y \qquad f_a = 36.00 \cdot ksi$$

*Allowable Bending Stress in the outer layer of the reinforcing (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)*

$f_{ss} \quad < \quad f_a$ ServiceStress = "OK!"

$$d_c = cover + \frac{1}{2} \cdot d_{stirrup} + \frac{1}{2} \cdot d_{bar\_A} \qquad d_c = 3.58 \cdot in$$

*"cover" is measured to center of shear reinforcement.*

Exposure Condition Factor:

$\gamma_e = 1.00$

*For class 1 exposure conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e$ = 0.75). (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$$\beta_s = 1 + \frac{d_c}{0.7 \cdot (h_{cap} - d_c)} \qquad \beta_s = 1.06$$

$s_{max}$ = minimum of:

$$\frac{700\gamma_e}{\beta_s \cdot f_{ss}} - 2d_c = 49.38 \cdot in$$

*(AASHTO LRFD Eq. 5.7.3.4-1)*

& 12in

*A good practice is to place a bar every 12in along each surface of the bent. (TxSP)*

$s_{max} = 12.00 \cdot in$

$$s_{Actual} = \frac{b_{stem} - 2 \cdot \left(cover + \frac{1}{2} \cdot d_{stirrup} + \frac{1}{2} \cdot d_{bar\_A}\right)}{BarANo - 1}$$

$s_{Actual} = 7.96 \cdot in \quad < \quad s_{max}$ ServiceabilityCheck = "OK!"

### Check Dead Load *BDM-LRFD, Chapter 4, Section 5, Design Criteria*

Check allowable $M_{dl}$: $f_{dl} = 22ksi$

*TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load.*

$$M_a = A_s \cdot d \cdot j \cdot f_{dl} \cdot \frac{1ft}{12in} \qquad M_a = 1116.04 \cdot kip \cdot ft$$

*Allowable Dead Load Moment*

$M_{dl} = 379.40 \cdot kip \cdot ft \quad < \quad M_a$ DeadLoadMom = "OK!"

## Flexural Reinforcement for Positive Bending (Bars B) (Tension in Bottom)

$M_{dl} = M_{posDL}$ $M_{dl} = 250.1 \cdot kip \cdot ft$

$M_s = M_{posServ}$ $M_s = 492.5 \cdot kip \cdot ft$ *From Cap 18 Output. See Pg. 10*

$M_u = M_{posUlt}$ $M_u = 741.7 \cdot kip \cdot ft$

### Minimum Flexural Reinforcement *(AASHTO LRFD 5.7.3.3.2)*

Factored Flexural Resistance, $M_r$, must be greater than or equal to the lesser of 1.2 $M_{cr}$ (Cracking Moment) or 1.33 Mu (Ultimate Moment)

$y_t = ybar$ $y_t = 33.80 \cdot in$ *Distance to the Center of Gravity of the Cap from the top of the Cap See Pg. 6 for calculations of "ybar"*

$S = \frac{I_g}{y_t}$ $S = 8.62 \times 10^4 \cdot in^3$ *Section Modulus for the extreme tension fiber*

$M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ $M_{cr} = 3269.9 \cdot kip \cdot ft$ *Cracking Moment (AASHTO LRFD Eq. 5.7.3.3.2-1)*

$M_f$ = minimum of: *Design for the lesser of 1.2$M_{cr}$ or 1.33Mu when determining minimum area of steel required.*

$1.2 \cdot M_{cr} = 3923.9 \cdot kip \cdot ft$

$1.33 \cdot M_u = 986.5 \cdot kip \cdot ft$

Thus, $M_r$ must be greater than $M_f = 986.5 \cdot kip \cdot ft$

### Moment Capacity Design *(AASHTO LRFD 5.7.3.2)*

Try, 11 ~ #11's Bottom

$BarBNo = 11$ *Number of bars in tension*

$d_{bar\_B} = 1.41in$ *Diameter of main reinforcing bars*

$A_{bar\_B} = 1.56in^2$ *Area of one main reinforcing bar*

$A_s = (BarBNo) \cdot A_{bar\_B}$ $A_s = 17.16 \cdot in^2$ *Area of steel in tension*

$d = d_{s\_pos}$ $d = 81.42 \cdot in$ *See Pg. 18 for the calculation of "$d_{s\_pos}$."*

$b = b_{stem}$ $b = 39 \cdot in$ *See Pg. 3 for the calculation of "$b_{stem}$."*

$c = \frac{A_s \cdot f_y}{0.85 \cdot f_c \cdot \beta_1 \cdot b}$ $c = 10.15 \cdot in$ *Depth of Cross Section under Compression under Ultimate Load (AASHTO LRFD Eq. 5.7.3.1.2-4)*

*This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.*

$a = c \cdot \beta_1$ $a = 8.63 \cdot in$ *Depth of Equivalent Stress Block (AASHTO LRFD 5.7.2.2)*

*Note: "a" is less than "$d_{stem}$" therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "$d_{stem}$" it would act over a Tee shaped area.*

$M_n = A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right) \cdot \frac{1ft}{12in}$ $M_n = 6615.7 \cdot kip \cdot ft$ *Nominal Flexural Resistance (AASHTO LRFD Eq. 5.7.3.2.2-1)*

## Flexural Reinforcement for Positive Bending (Con't) (Bars B)

### Moment Capacity Design (Con't)

$\varepsilon_s = 0.003 \cdot \frac{d - c}{c}$ $\qquad \varepsilon_s = 0.021$ *Strain in Reinforcing at Ultimate*

$\varepsilon_s > 0.005$

FlexureBehavior = "Tension Controlled" *(AASHTO LRFD 5.7.2.1)*

$\phi_M = 0.90$ *(AASHTO LRFD 5.5.4.2.1)*

$M_r = \phi_M \cdot M_n$ $\qquad M_r = 5954.1 \cdot kip \cdot ft$ *Factored Flexural Resistance (AASHTO LRFD Eq. 5.7.3.2.1-1)*

$M_u = 741.7 \cdot kip \cdot ft < M_r$ $\qquad$ MinReinfChk = "OK!"

$M_f = 986.5 \cdot kip \cdot ft < M_r$ $\qquad$ UltimateMom = "OK!"

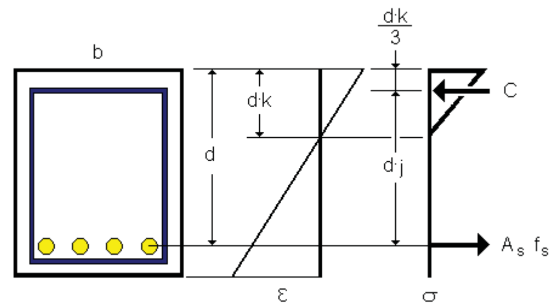
### Check Serviceability *(AASHTO LRFD 5.7.3.4)*

To find $s_{max}$ :

$d_c = cover + \frac{1}{2} \cdot d_{stirrup} + \frac{1}{2} \cdot d_{bar\_B}$ $\qquad d_c = 3.58 \cdot in$ *"cover" is measured to center of shear reinforcement.*

Tension Reinforcement Ratio:

*For service loads, the stress on the cross-section is located as drawn:*




$\rho = \frac{A_s}{b \cdot d}$ $\qquad \rho = 0.0054$

$k = \sqrt{(2 \cdot \rho \cdot n) + (\rho \cdot n)^2} - (\rho \cdot n)$ $\qquad k = 0.259$

$d \cdot k = 21.10 \cdot in < d_{stem} = 57.00 \cdot in$

Therefore, the compression force acts over a rectangular area.

$j = 1 - \frac{k}{3}$ $\qquad j = 0.914$

$f_{ss} = \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12in}{1ft}$ $\qquad f_{ss} = 4.63 \cdot ksi$ *Service Load Bending Stress in outer layer of the reinforcing*

$f_a = 0.6 \cdot f_y$ $\qquad f_a = 36.00 \cdot ksi$ *Allowable Bending Stress in the outer layer of the reinforcing (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)*

$f_{ss} < f_a$ $\qquad$ ServiceStress = "OK!"

Exposure Condition Factor:

$\gamma_e = 1.00$ *For class 1 exposure conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e$ = 0.75). (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)*

$\beta_s = 1 + \frac{d_c}{0.7 \cdot (h_{cap} - d_c)}$ $\qquad \beta_s = 1.06$

$s_{max}$ = minimum of:

$\frac{700\gamma_e}{\beta_s \cdot f_{ss}} - 2d_c = 135.09 \cdot in$ *(AASHTO LRFD Eq. 5.7.3.4-1)*

& 12in *A good practice is to place a bar every 12in along each surface of the bent. (TxSP)*

$s_{max} = 12.00 \cdot in$

## Flexural Reinforcement for Positive Bending (Con't) (Bars B)

### Check Serviceability (Con't)

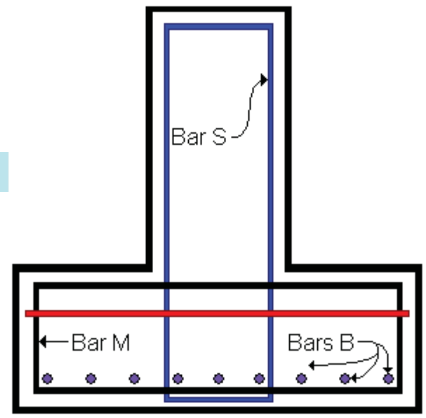
#### Bars Inside Stirrup Bar S

*Number of bars B that are inside Stirrup bar S.*

Try: $BarBInsideSNo = 5$

$$s_{Actual} = \frac{b_{stem} - 2\cdot\left(cover + \frac{1}{2}\cdot d_{bar\_S} + \frac{1}{2}\cdot d_{bar\_B}\right)}{BarBInsideSNo - 1}$$

$s_{Actual} = 7.96\cdot in$ < $s_{max}$ ServiceabilityCheck = "OK!"




#### Bars Outside Stirrup Bar S

*Number of bars B that are Outside Stirrup bar S.*

$BarBOutsideSNo = BarBNo - BarBInsideSNo$

$BarBOutsideSNo = 6$

$$s_{Actual} = \frac{2b_{ledge} + 2\cdot\left(cover + \frac{1}{2}d_{bar\_S} + \frac{1}{2}\cdot d_{bar\_B} - cover - \frac{1}{2}d_{bar\_M} - \frac{1}{2}\cdot d_{bar\_B}\right)}{BarBOutsideSNo}$$

$s_{Actual} = 8.67\cdot in$ < $s_{max}$ ServiceabilityCheck = "OK!"

### Check Dead Load *BDM-LRFD, Chapter 4, Section 5, Design Criteria*

Check allowable $M_{dl}$: $f_{dl} = 22ksi$

*TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load.*

$$M_a = A_s\cdot d\cdot j\cdot f_{dl}\cdot\frac{1ft}{12in}$$

$M_a = 2340.19\cdot kip\cdot ft$ *Allowable Dead Load Moment*

$M_{dl} = 250.10\cdot kip\cdot ft$ < $M_a$ DeadLoadMom = "OK!"

## Flexural Steel Summary:

Use 5~#11 Bars on Top
& 11~#11 Bars on Bottom

## Ledge Reinforcement (Bars M&N)

Try Bars M at a 4.95" spacing, and Bars N at a 9.90" spacing.

*Use trial and error to determine the spacing needed for the ledge reinforcing. Bars M @ 5" and Bars N @ 10" failed one of the checks by a small margin (1%). 4.95" spacing was chosen because it shoud pass all the checks.*

*It is typical for Bars N to be at every other Bar M.*

$s_{bar\_M} = 4.95in$

$s_{bar\_N} = 9.90in$

### Determine Distribution Widths

These distribution widths will be used on the following three pages to determine the required ledge reinforcement per foot of cap.

Distribution Width for Shear *(AASHTO LRFD 5.13.2.5.2)*

*Note: These are the same distribution widths used for the Shear Friction check on Pg. 22.*

Interior Girders

$b_{s\_Int}$ = minimum of:

$W + 4\ a_v = 69.00 \cdot in$

$S = 96.00 \cdot in$

*"S" is the girder spacing. (From Pg. 6)*

$b_{s\_Int} = 69.00 \cdot in$

Exterior Girders

$b_{s\_Ext}$ = minimum of:

$W + 4\ a_v = 69.00 \cdot in$

$S = 96.00 \cdot in$

$2\ c = 48.00 \cdot in$

*"c" is the distance from the center of bearing of the outside beam to the end of the ledge. (From Pg. 6)*

$b_{s\_Ext} = 48.00 \cdot in$

Distribution Width for Bending and Axial Loads *(AASHTO LRFD 5.13.2.5.3)*

Interior Girders

$b_{m\_Int}$ = minimum of:

$W + 5\ a_f = 93.50 \cdot in$

$S = 96.00 \cdot in$

$b_{m\_Int} = 93.50 \cdot in$

Exterior Girders

$b_{m\_Ext}$ = minimum of:

$W + 5\ a_f = 93.50 \cdot in$

$S = 96.00 \cdot in$

$2\ c = 48.00 \cdot in$

$b_{m\_Ext} = 48.00 \cdot in$

## Ledge Reinforcement (Con't)     (Bars M&N)

The reinforcing required for shear friction, flexure, and axial tension will be calculated on Pgs. 30-32. The reinforcing provided by Bars M and Bars N must exceed the checks that are found on the bottom of Pg. 32 (These checked can be found on pages 33 and 34). These checks combine the reinforcing requirements for shear friction, flexure, and axial tension, as per AASHTO LRFD 5.13.2.4.2.

### Reinforcing Required for Shear Friction *(AASHTO LRFD 5.8.4.1)*

$\phi = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

$\mu = 1.4 \quad c_1 = 0\text{ksi} \quad P_c = 0\text{kip}$

*"$\mu$" is 1.4 for monolithically placed concrete. (AASHTO LRFD 5.8.4.3)*

Recall: $d_e = 25.5 \cdot in$ *(From Pg. 18)*

*For clarity, the cohesion factor is labeled "$c_1$". This is to prevent confusion with "c", the distance from the last girder to the edge of the cap. $c_1$ is 0ksi for corbels and ledges. (AASHTO LRFD 5.8.4.3)*

#### Minimum Reinforcing *(AASHTO LRFD 5.8.4.4-1)*

$$A_{vf\_min} = \frac{0.05\ ksi \cdot A_{cv}}{f_y}$$

$A_{cv} = d_e \cdot b_s$ and $a_{vf} = \frac{A_{vf}}{b_s}$

*"$P_c$" is zero as there is no axial compression.*

$$a_{vf\_min} = \frac{0.05\ ksi \cdot d_e}{f_y} \qquad a_{vf\_min} = 0.26 \cdot \frac{in^2}{ft}$$

*Minimum Reinforcing required for Shear Friction*

#### Interior Girders

$A_{cv} = d_e \cdot b_{s\_Int} \qquad A_{cv} = 1759 \cdot in^2$

$V_{u\_Int} = 322 \cdot kip$ *From Pg. 16*

$V_n = c_1 \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ *(AASHTO LRFD Eq. 5.8.4.1-3)*

$\phi V_n \geq Vu$ *(AASHTO LRFD Eq. 5.8.4.1-1 & AASHTO LRFD Eq. 5.8.4.1-2)*

$\phi \cdot \left[c_1 \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)\right] \geq V_u$

$A_{vf} = \left[(V_{u\_Int} \div \phi - c_1 \cdot A_{cv}) \div \mu - P_c\right] \div f_y \qquad A_{vf} = 4.26 \cdot in^2$

*Required Reinforcing for Shear Friction*

$$a_{vf\_Int} = \frac{A_{vf}}{b_{s\_Int}} \qquad a_{vf\_Int} = 0.74 \cdot \frac{in^2}{ft}$$

*Required Reinforcing for Shear Friction per foot length of cap*

#### Exterior Girders

$A_{cv} = d_e \cdot b_{s\_Ext} \qquad A_{cv} = 1224 \cdot in^2$

$V_{u\_Ext} = 322 \cdot kip$ *From Pg. 16*

$V_n = c_1 \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)$ *(AASHTO LRFD Eq. 5.8.4.1-3)*

$\phi V_n \geq Vu$ *(AASHTO LRFD Eq. 5.8.4.1-1 & AASHTO LRFD Eq. 5.8.4.1-2)*

$\phi \cdot \left[c_1 \cdot A_{cv} + \mu \cdot (A_{vf} \cdot f_y + P_c)\right] \geq V_u$

$A_{vf} = \left[(V_{u\_Ext} \div \phi - c_1 \cdot A_{cv}) \div \mu - P_c\right] \div f_y \qquad A_{vf} = 4.26 \cdot in^2$

*Required Reinforcing for Shear Friction*

$$a_{vf\_Ext} = \frac{A_{vf}}{b_{s\_Ext}} \qquad a_{vf\_Ext} = 1.06 \cdot \frac{in^2}{ft}$$

*Required Reinforcing for Shear Friction per foot length of cap*

## Ledge Reinforcement (Con't) (Bars M&N)

### Reinforcing Required for Flexure *(AASHTO LRFD 5.13.2.4.1)*

Recall: $h = 29.50 \cdot in$ $d_e = 25.5 \cdot in$ $a_v = 12.00 \cdot in$ *From Pg. 18*

Interior Girders

$V_{u\_Int} = 322 \cdot kip$ *From Pg. 16*

$N_{uc\_Int} = 0.2 \cdot V_{u\_Int}$ $N_{uc\_Int} = 64.37 \cdot kip$ *(AASHTO LRFD 5.13.2.4.1)*

$M_{u\_Int} = V_{u\_Int} \cdot a_v + N_{uc\_Int} \cdot (h - d_e)$ $M_{u\_Int} = 343.3 \cdot kip \cdot ft$ *(AASHTO LRFD Eq. 5.13.2.4.1-1)*

Use the below equations to solve for $A_f$:

$\phi M_n \geq M_{u\_Int}$ *(AASHTO LRFD Eq. 1.3.2.1-1)*

$M_n = A_f \cdot f_y \cdot \left(d_e - \frac{a}{2}\right)$ *(AASHTO LRFD Eq. 5.7.3.2.2-1)*

$c = \frac{A_f \cdot f_y}{0.85 \cdot f_c \cdot \beta_1 \cdot b_{m\_Int}}$ *(AASHTO LRFD Eq. 5.7.3.1.2-4) This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.*

$\beta_1 = 0.85$

$a = c \cdot \beta_1$ *(AASHTO LRFD Eq. 5.7.2.2)*

$\phi = 0.65 - 0.15 \cdot \left(\frac{d_e}{c} - 1\right)$ Bounded by: $0.75 \leq \phi \leq 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

Solve for $A_f$: $A_f = 3.03 \cdot in^2$ *Required Reinforcing for Flexure*

$a_{f\_Int} = \frac{A_f}{b_{m\_Int}}$ $a_{f\_Int} = 0.39 \cdot \frac{in^2}{ft}$ *Required Reinforcing for Flexure per foot length of cap*

Exterior Girders

$V_{u\_Ext} = 322 \cdot kip$ *From Pg. 16*

$N_{uc\_Ext} = 0.2 \cdot V_{u\_Ext}$ $N_{uc\_Ext} = 64.37 \cdot kip$ *(AASHTO LRFD 5.13.2.4.1)*

$M_{u\_Ext} = V_{u\_Ext} \cdot a_v + N_{uc\_Ext} \cdot (h - d_e)$ $M_{u\_Ext} = 343.3 \cdot kip \cdot ft$ *(AASHTO LRFD Eq. 5.13.2.4.1-1)*

Use the below equations to solve for $A_f$:

$\phi M_n \geq M_{u\_Ext}$ *(AASHTO LRFD Eq. 1.3.2.1-1)*

$M_n = A_f \cdot f_y \cdot \left(d_e - \frac{a}{2}\right)$ *(AASHTO LRFD Eq. 5.7.3.2.2-1)*

$c = \frac{A_f \cdot f_y}{0.85 \cdot f_c \cdot \beta_1 \cdot b_{m\_Ext}}$ *(AASHTO LRFD Eq. 5.7.3.1.2-4) This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.*

$\beta_1 = 0.85$

$a = c \cdot \beta_1$ *(AASHTO LRFD Eq. 5.7.2.2)*

$\phi = 0.65 - 0.15 \cdot \left(\frac{d_e}{c} - 1\right)$ Bounded by: $0.75 \leq \phi \leq 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

Solve for $A_f$: $A_f = 3.07 \cdot in^2$ *Required Reinforcing for Flexure*

$a_{f\_Ext} = \frac{A_f}{b_{m\_Ext}}$ $a_{f\_Ext} = 0.77 \cdot \frac{in^2}{ft}$ *Required Reinforcing for Flexure per foot length of cap*

## Ledge Reinforcement (Con't) (Bars M&N)

### Reinforcing Required for Axial Tension *(AASHTO LRFD 5.13.2.4.2)*

$\phi = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

Interior Girders

$N_{uc\_Int} = 64.37 \cdot kip$ *From Pg. 31*

$A_n = \frac{N_{uc\_Int}}{\phi \cdot f_y}$ $A_n = 1.19 \cdot in^2$ *Required Reinforcing for Axial Tension (AASHTO LRFD Eq. 5.13.2.4.2-7)*

$a_{n\_Int} = \frac{A_n}{b_{m\_Int}}$ $a_{n\_Int} = 0.15 \cdot \frac{in^2}{ft}$ *Required Reinforcing for Axial Tension per foot length of cap*

Exterior Girders

$N_{uc\_Ext} = 64.37 \cdot kip$ *From Pg. 31*

$A_n = \frac{N_{uc\_Ext}}{\phi \cdot f_y}$ $A_n = 1.19 \cdot in^2$ *Required Reinforcing for Axial Tension (AASHTO LRFD Eq. 5.13.2.4.2-7)*

$a_{n\_Ext} = \frac{A_n}{b_{m\_Ext}}$ $a_{n\_Ext} = 0.30 \cdot \frac{in^2}{ft}$ *Required Reinforcing for Axial Tension per foot length of cap*

### Minimum Reinforcing *(AASHTO LRFD 5.13.2.4.1)*

$a_{s\_min} = 0.04 \cdot \frac{f_c}{f_y} \cdot d_e$ $a_{s\_min} = 0.73 \cdot \frac{in^2}{ft}$ *Minimum Required Reinforcing (AASHTO LRFD 5.13.2.4.1)*

### Check Required Reinforcing *(AASHTO LRFD 5.13.2.4)*

Actual Reinforcing:

$a_s = \frac{A_{bar\_M}}{s_{bar\_M}}$ $a_s = 1.07 \cdot \frac{in^2}{ft}$ *Primary Ledge Reinforcing Provided*

$a_h = \frac{A_{bar\_N}}{s_{bar\_N}}$ $a_h = 0.53 \cdot \frac{in^2}{ft}$ *Auxiliary Ledge Reinforcing Provided*

*The area of one bar M and N can be found on Pg. 18. The spacing of bars M and N can be found on Pg. 29.*

Checks:

$A_s \ge A_{s\_min}$ *(AASHTO LRFD 5.13.2.4.1)*

$A_s \ge A_f + A_n$ *(AASHTO LRFD 5.13.2.4.2)*

$A_s \ge \frac{2 \cdot A_{vf}}{3} + A_n$ *(AASHTO LRFD Eq. 5.13.2.4.2-5)*

$A_h \ge 0.5 \cdot (A_s - A_n)$ *(AASHTO LRFD Eq. 5.13.2.4.2-6)*

## Ledge Reinforcement (Con't) (Bars M&N)

### Check Required Reinforcing (Con't)

The following checks bars M and N. These are the checks found on Pg. 32, modified to check the steel per unit length instead of the total steel.

Check Interior Girders

Bar M:

Check if: $a_s \geq a_{s\_min}$ *(AASHTO LRFD 5.13.2.4.1)*

$a_s \geq a_{f\_Int} + a_{n\_Int}$ *(AASHTO LRFD 5.13.2.4.2)*

$a_s \geq \frac{2 \cdot a_{vf\_Int}}{3} + a_{n\_Int}$ *(AASHTO LRFD Eq. 5.13.2.4.2-5)*

$$a_s = 1.07 \cdot \frac{in^2}{ft}$$

$$a_{s\_min} = 0.73 \cdot \frac{in^2}{ft} \quad < \quad a_s$$

$$a_{f\_Int} + a_{n\_Int} = 0.54 \cdot \frac{in^2}{ft} \quad < \quad a_s$$

$$\frac{2 \cdot a_{vf\_Int}}{3} + a_{n\_Int} = 0.65 \cdot \frac{in^2}{ft} \quad < \quad a_s$$

BarMCheck = "OK!"

Bar N:

Check if: $a_h \geq 0.5 \cdot (a_s - a_{n\_Int})$ *(AASHTO LRFD Eq. 5.13.2.4.2-6)*

$a_s$ = The maximum of:

$a_{f\_Int} + a_{n\_Int}$

$\frac{2 \cdot a_{vf\_Int}}{3} + a_{n\_Int}$

*"$a_s$" in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.13.2.4.2.*
*This is derived from the suggestion that $A_h$ should not be less than $A_f/2$ nor less than $A_{vf}/3$ (Furlong & Mirza pg. 73 & 74)*

$$a_s = 0.54 \cdot \frac{in^2}{ft}$$

$$a_h = 0.53 \cdot \frac{in^2}{ft}$$

$$0.5 \cdot (a_s - a_{n\_Int}) = 0.19 \cdot \frac{in^2}{ft} \quad < \quad a_h$$

BarNCheck = "OK!"

## Ledge Reinforcement (Con't) (Bars M&N)

### Check Required Reinforcing (Con't)

#### Check Exterior Girders

Bar M

Check if: $a_s \geq a_{s\_min}$ *(AASHTO LRFD 5.13.2.4.1)*

$a_s \geq a_{f\_Ext} + a_{n\_Ext}$ *(AASHTO LRFD 5.13.2.4.2)*

$a_s \geq \frac{2 \cdot a_{vf\_Ext}}{3} + a_{n\_Ext}$ *(AASHTO LRFD Eq. 5.13.2.4.2-5)*

$a_s = 1.07 \cdot \frac{in^2}{ft}$

$a_{s\_min} = 0.73 \cdot \frac{in^2}{ft} \quad < \quad a_s$

$a_{f\_Ext} + a_{n\_Ext} = 1.06 \cdot \frac{in^2}{ft} \quad < \quad a_s$

$\frac{2 \cdot a_{vf\_Ext}}{3} + a_{n\_Ext} = 1.01 \cdot \frac{in^2}{ft} \quad < \quad a_s$

BarMCheck = "OK!"

Bar N

Check if: $a_h \geq 0.5 \cdot \left(a_s - a_{n\_Int}\right)$ *(AASHTO LRFD Eq. 5.13.2.4.2-6)*

*"$a_s$" in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.13.2.4.2.*
*This is derived from the suggestion that $A_h$ should not be less than $A_f/2$ nor less than $A_{vf}/3$ (Furlong & Mirza pg. 73 & 74)*

$a_s$ = The maximum of:

$a_{f\_Int} + a_{n\_Int}$

$\frac{2 \cdot a_{vf\_Int}}{3} + a_{n\_Int}$

$a_s = 1.06 \cdot \frac{in^2}{ft}$

$a_h = 0.53 \cdot \frac{in^2}{ft}$

$0.5 \cdot \left(a_s - a_{n\_Int}\right) = 0.46 \cdot \frac{in^2}{ft} \quad < \quad a_h$

BarNCheck = "OK!"

**Ledge Reinforcement Summary:** Use #6 primary ledge reinforcing @ 4.95" maximum spacing & #6 auxiliary ledge reinforcing @ 9.90" maximum spacing

## Hanger Reinforcement (Bars S)

Try Double # 6 Stirrups at a 8" spacing.

*Use trial and error to determine the spacing needed for the hanger reinforcing.*

$s_{bar\_S} = 8.5in$

$A_{hr} = 2stirrups \cdot A_{bar\_S}$ $\quad A_{hr} = 0.88 \cdot in^2$

$A_v = 2legs \cdot A_{hr}$ $\quad A_v = 1.76 \cdot in^2$

*$A_{hr}$ is the area of one leg of hanger reinforcement. In this example the area of the bar is multiplied by 2 because the Inverted Tee has double stirrups.*

### Check Minimum Transverse Reinforcement

$b_v = b_{stem}$ $\quad b_v = 39.00 \cdot in$

$$A_{v\_min} = 0.0316 \cdot \sqrt{f_c} \cdot \frac{b_v \cdot s_{bar\_S}}{f_y} \qquad A_{v\_min} = 0.33 \cdot in^2$$

*(AASHTO LRFD Eq. 5.8.2.5-1)*

$A_v = 1.76 \cdot in^2 \quad > \quad A_{v\_min}$ $\quad$ MinimumSteelCheck = "OK!"

### Check Service Limit State

*(AASHTO LRFD 5.13.2.5.5 with modifications from BDM-LRFD Ch.4, Sect. 5, Design Criteria)*

#### Interior Girders

*TxDOT uses "$^2/_3 f_y$" from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 $f_y$" from AASHTO LRFD Eq. 5.13.2.5.5-1.*

$V_{all}$ = minimum of:

$$\frac{A_{hr} \cdot \left(\frac{2}{3} \cdot f_y\right)}{s_{bar\_S}} \cdot \left(W + 3 \cdot a_v\right) = 236 \cdot kip$$

*(BDM-LRFD Ch.4, Sect. 5, Design Criteria)*

$$\frac{A_{hr} \cdot \left(\frac{2}{3} \cdot f_y\right)}{s_{bar\_S}} \cdot S = 398 \cdot kip$$

*(BDM-LRFD Ch.4, Sect. 5, Design Criteria ~ Modified to limit the distribution width to the girder spacing. This will prevent distribution widths from overlapping)*

$V_{all} = 236 \cdot kip$

$V_{s\_Int} = 215 \cdot kip \quad < \quad V_{all}$ $\quad$ ServiceCheck = "OK!"

#### Exterior Girders

$V_{all}$ = minimum of:

$V_{all}$ for the interior girder

$$\frac{A_{hr} \cdot \left(\frac{2}{3} \cdot f_y\right)}{s_{bar\_S}} \cdot \left(\frac{W + 3 \cdot a_v}{2} + c\right) = 217 \cdot kip$$

*(BDM-LRFD Ch.4, Sect. 5, Design Criteria ~ Modified to limit the distribution width to the edge of the cap. This will prevent distribution widths from extending over the edge of the cap.)*

$$\frac{A_{hr} \cdot \left(\frac{2}{3} \cdot f_y\right)}{s_{bar\_S}} \cdot \left(\frac{S}{2} + c\right) = 298 \cdot kip$$

*(BDM-LRFD Ch.4, Sect. 5, Design Criteria ~ Modified to limit the distribution width to half the girder spacing and the distance to the edge of the cap. This will prevent distribution widths from overlapping or extending over the edge of the cap.)*

$V_{all} = 217 \cdot kip$

$V_{s\_Ext} = 215 \cdot kip \quad < \quad V_{all}$ $\quad$ ServiceCheck = "OK!"

## <u>Hanger Reinforcement</u> (Con't) (Bars S)

### Check Strength Limit State *(AASHTO LRFD 5.13.2.5.5)*

$\phi = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

<u>Interior Girders</u>

$V_n$ = minimum of:

$$\frac{A_{hr} \cdot f_y}{s_{bar\_S}} \cdot S = 596 \cdot kip$$ *(AASHTO LRFD Eq. 5.13.2.5.5-2)*

$$\left(0.063 \cdot \sqrt{f_c} \cdot b_f \cdot d_f\right) + \frac{A_{hr} \cdot f_y}{s_{bar\_S}} \cdot \left(W + 2 \cdot d_f\right) = 699 \cdot kip$$ *(AASHTO LRFD Eq. 5.13.2.5.5-3)*

$V_n = 596 \cdot kip$

$\phi V_n = 537 \cdot kip$

$V_{u\_Int} = 322 \cdot kip \quad < \quad \phi V_n$ UltimateCheck = "OK!"

<u>Exterior Girders</u>

$V_n$ = minimum of:

$V_n$ for the interior girder

$$\frac{A_{hr} \cdot f_y}{s_{bar\_S}} \cdot \left(\frac{S}{2} + c\right) = 447 \cdot kip$$ *(AASHTO LRFD Eq. 5.13.2.5.5-2) Modified to limit the distribution width to the edge of the cap.*

$$\left(0.063 \cdot \sqrt{f_c} \cdot b_f \cdot d_f\right) + \frac{A_{hr} \cdot f_y}{s_{bar\_S}} \cdot \left(\frac{W + 2 \cdot d_f}{2} + c\right) = 632 \cdot kip$$ *(AASHTO LRFD Eq. 5.13.2.5.5-3) Modified to limit the distribution width to the edge of the cap.*

$V_n = 447 \cdot kip$

$\phi V_n = 403 \cdot kip$

$V_{u\_Ext} = 322 \cdot kip \quad < \quad \phi V_n$ UltimateCheck = "OK!"

## Hanger Reinforcement (Con't) (Bars S)

### Combined Shear and Torsion

*The following calculations are for Station 36. All critical locations must be checked. See the the Concrete Section Shear Capacity spreadsheet in the appendices for calculations at other locations. Shear and Moments were calculated using the CAP 18 program.*

$M_u = 335.6kip \cdot ft$ $V_u = 448.1 \cdot kip$ $N_u = 0kip$ $T_u = 660 \cdot kip \cdot ft$ *These loads can be found on Pg. 16*

Recall: $\beta_1 = 0.85$ $f_y = 60 \cdot ksi$

$f_c = 3.6 \cdot ksi$ $E_s = 29000 \cdot ksi$

$b_f = 91 \cdot in$ $h_{cap} = 85 \cdot in$ $b_{stem} = 39 \cdot in$

$b_v = b_{stem}$ $b_v = 39.00 \cdot in$

Find $d_v$:

$A_s = A_{bar\_A} \cdot BarANo$ $A_s = 7.80 \cdot in^2$

*The Moment calculations to the left reiterate those on Pg. 24.*

*Shears are maximum near the column faces. In these regions the cap is in negative bending with tension in the top of the cap. Therefore, the calculations are based on the steel in the top of the bent cap.*

$$c = \frac{A_s \cdot f_y}{0.85 \cdot f_c \cdot \beta_1 \cdot b_f}$$ $c = 1.98 \cdot in$

$a = c \cdot \beta_1$ $a = 1.68 \cdot in$

$d_s = d_{s\_neg}$ $d = 81.42 \cdot in$

$$M_n = A_s \cdot f_y \cdot \left(d - \frac{a}{2}\right)$$ $M_n = 3142.6 \cdot kip \cdot ft$

$A_{ps} = 0in^2$

$$d_e = \frac{A_{ps} \cdot f_{ps} \cdot d_p + A_s \cdot f_y \cdot d_s}{A_{ps} \cdot f_{ps} + A_s \cdot f_y}$$ $d_e = 81.42 \cdot in$ *(AASHTO LRFD Eq. 5.8.2.9-2)*

$d_v$ need <u>not</u> be <u>less</u> than the <u>greater</u> of $0.9d_e$ and 0.72h: *(AASHTO LRFD 5.8.2.9)*

$d_v$ = maximum of:

$$\frac{M_n}{A_s \cdot f_y + A_{ps} \cdot f_{ps}} = 80.58 \cdot in$$ *(AASHTO LRFD Eq. C5.8.2.9-1)*

$0.9 \cdot d_e = 73.28 \cdot in$

$0.72 \cdot h = 21.24 \cdot in$

$d_v = 80.58 \cdot in$

The method for calculating θand β used in this design example are from AASHTO LRFD Appendix B5. The method from AASHTO LRFD 5.8.3.4.2 may be used instead. The method from 5.8.3.4.2 is based on the method from Appendix B5; however, it is less accurate and more conservative (often excessively conservative). The method from Apendix B5 is preferred because it is more accurate, but it requires iterating to a solution. The method from 5.8.3.4.2 can be used when doing calculations by hand.

## Hanger Reinforcement (Con't) (Bars S)

### Check Combined Shear and Torsion (Con't)

Determine θ and β:

$\phi_v = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

$v_u = \dfrac{\left|V_u - (\phi_v \cdot V_p)\right|}{\phi_v \cdot b_v \cdot d_v}$ $v_u = 0.16 \cdot ksi$

*Shear Stress on the Concrete (AASHTO LRFD Eq. 5.8.2.9-1)*

$\dfrac{v_u}{f_c} = 0.04$

Using Table B5.2-1 with $\dfrac{v_u}{f_c} = 0.04$ and $\varepsilon_x = 0.001$

$\theta = 36.4\ deg$ and $\beta = 2.23$

*Determining θ and β is an iterative process, therefore, assume initial shear strain value $\varepsilon_x$ of 0.001 per LRFD B5.2 and then verify that the assumption was valid.*

$$\varepsilon_x = \frac{\left(\dfrac{|M_u|}{d_v} + 0.5\ N_u + 0.5\ |V_u - V_p|\ \cot(\theta) - A_{ps} \cdot f_{po}\right)}{2\left(E_s \cdot A_s + E_p \cdot A_{ps}\right)}$$

*Strain halfway between the compressive and tensile resultants (AASHTO LRFD Eq. B5.2-1)*

where, $|M_u| = 335.60 \cdot kip \cdot ft$ Must be > $|V_u - V_p| \cdot d_v = 3008.98 \cdot kip \cdot ft$

*If $\varepsilon_x$ < 0, then use equation B5.2-3 and re-solve for $\varepsilon_x$.*

$\varepsilon_x = 1.66 \cdot 10^{-3} \dfrac{in}{in}$ > $1.00 \times 10^{-3} \dfrac{in}{in}$

use $\varepsilon_x = 1.00 \times 10^{-3} \dfrac{in}{in}$

*For values of $\varepsilon_x$ greater than 0.001, the tensile strain in the reinforcing, $\varepsilon_t$ is greater than 0.002. ($\varepsilon_t = 2\ \varepsilon_x - \varepsilon_c$ , where $\varepsilon_c$ is < 0) Grade 60 steel yields at a strain of 60 ksi / 29,000 ksi = 0.002. By limiting the tensile strain in the steel to the yield strain and using the Modulus of Elasticity of the steel prior to yield, this limits the tensile stress of the steel to the yield stress. $\varepsilon_x$ has not changed from the assumed value, therefore no iterations are required.*

$V_p = 0kip$

*"$V_p$" is zero as there is no prestressing.*

$A_c = b_{stem} \cdot \dfrac{h_{cap}}{2}$ $A_c = 1657.5 \cdot in^2$

$s = s_{bar\_S}$ $s = 8.50 \cdot in$

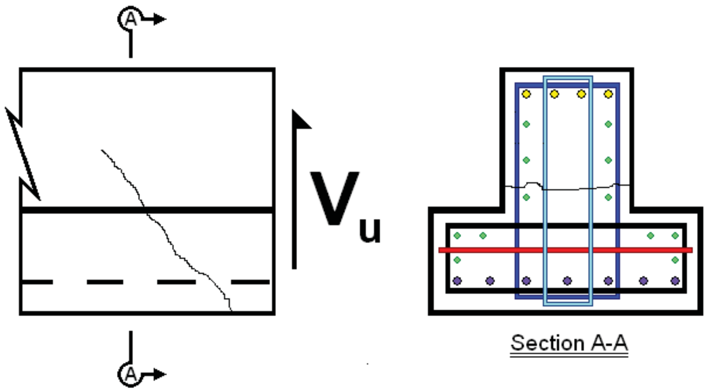
*(AASHTO LRFD B5.2) "$A_c$" is the area of concrete on the flexural tension side of the cap, from the extreme tension fiber to one half the cap depth. "$A_c$" is needed if AASHTO LRFD Eq. B5.2-1 is negative.*

## Hanger Reinforcement (Con't) (Bars S)

### Check Combined Shear and Torsion (Con't)

$A_v = 2\ legs \cdot 2\ stirrups \cdot A_{bar\_S}$ $\quad A_v = 1.76 \cdot in^2$

*The transverse reinforcement, "$A_v$", is double closed stirrups. The failure surface intersects four stirrup legs, therefore the area of the shear steel is four times the stirrup bar's area (0.44in²). See the sketch of the failure plane to the left.*




$A_t = 1leg \cdot A_{bar\_S}$ $\quad A_t = 0.44 \cdot in^2$

*"$A_t$" is the area of the outer stirrup. $A_t$ is not independent of $A_v$, but it is one leg of the outer stirrup of $A_v$.*

$A_{oh} = (d_{stem}) \cdot (b_{stem} - 2 \cdot cover) + (d_{ledge} - 2 \cdot cover) \cdot (b_f - 2 \cdot cover)$

*"$A_{oh}$" is the area inside the centerline of the exterior stirrup.*

$A_{oh} = 3916 \cdot in^2$

$A_o = 0.85 \cdot A_{oh}$ $\quad A_o = 3329 \cdot in^2$

*(AASHTO LRFD C5.8.2.1)*
*$A_o$ = 0.85 * the area inside the centerline of the exterior stirrup.*

$p_h = (b_{stem} - 2 \cdot cover) + 2 \cdot (b_{ledge}) + (b_f - 2 \cdot cover) + 2 \cdot (h_{cap} - 2 \cdot cover)$

*"$p_h$" is the perimeter of the centerline of Bar S.*

$p_h = 332.0 \cdot in$

### Equivalent Shear Force

$$V_{u\_Eq} = \sqrt{V_u^2 + \left(\frac{0.9 \cdot p_h \cdot T_u}{2 \cdot A_o}\right)^2} \qquad V_{u\_Eq} = 572.0 \cdot kip$$

*(AASHTO LRFD Eq. 5.8.2.1-6)*

### Shear Steel Required

$V_n$ = the lesser of:

$V_c + V_s + V_p$ *(AASHTO LRFD Eq. 5.8.3.3-1)*

$0.25 \cdot f_c \cdot b_v \cdot d_v + V_p$ *(AASHTO LRFD Eq. 5.8.3.3-2)*

check maximum $\phi V_n$ for section:

$\phi V_{n\_max} = \phi \cdot (0.25 \cdot f_c \cdot b_v \cdot d_v + V_p)$ $\quad \phi V_{n\_max} = 2546 \cdot kip$

$V_u = 448.1 \cdot kip \quad < \quad \phi V_{n\_max}$ $\quad$ MaxShearCheck = "OK!"

## Hanger Reinforcement (Con't) (Bars S)

### Check Combined Shear and Torsion (Con't)

Shear Steel Required (Con't)

calculate required shear steel:

$V_u \le \phi V_n$ *(AASHTO LRFD Eq. 1.3.2.1-1)*

$V_c = 0.0316 \cdot \beta \cdot \sqrt{f_c} \cdot b_v \cdot d_v$  $V_c = 420 \cdot kip$ *(AASHTO LRFD Eq. 5.8.3.3-3)*

$V_u \le \phi \left( V_c + V_s + V_p \right)$

$$V_s = \frac{A_v \cdot f_y \cdot d_v \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)}{s_{req}}$$ *(AASHTO LRFD Eq. 5.8.3.3-4)*

$$a_{v\_req} = \frac{\frac{V_u}{\phi_v} - V_c - V_p}{f_y \cdot d_v \cdot (\cot(\theta) + \cot(\alpha)) \cdot \sin(\alpha)} \qquad a_{v\_req} = 0.14 \cdot \frac{in^2}{ft}$$

Torsional Steel Required

$\phi_T = 0.9$ *(AASHTO LRFD 5.5.4.2.1)*

$T_u \le \phi_T \cdot T_n$ *(AASHTO LRFD Eq. 1.3.2.1-1)*

$$T_n = \frac{2 \cdot A_o \cdot A_t \cdot f_y \cdot \cot(\theta)}{s_{bar\_S}}$$ *(AASHTO LRFD Eq. 5.8.3.6.2-1)*

$$a_{t\_req} = \frac{T_u}{\phi_T \cdot 2 \cdot A_o \cdot f_y \cdot \cot(\theta)} \qquad a_{t\_req} = 0.19 \cdot \frac{in^2}{ft}$$

Total Required Transverse Steel *(AASHTO LRFD 5.8.3.6.1)*

$a_{req} = a_{v\_req} + 2\ sides \cdot a_{t\_req}$  $a_{req} = 0.53 \cdot \frac{in^2}{ft}$

$a_{prov} = \frac{A_v}{s_{bar\_S}}$  $a_{prov} = 2.48 \cdot \frac{in^2}{ft}$

*The transverse reinforcement is designed for the side of the section where the effects of shear and torsion are additive. (AASHTO LRFD C5.8.3.6.1) Both sides of the section need this reinforcing because the torsion can act on either side of the section.*

$a_{prov} > a_{req}$  TransverseSteelCheck = "OK"

## Hanger Reinforcement (Con't) (Bars S)

### Maximum Spacing of Transverse Reinforcement *(AASHTO LRFD 5.8.2.7)*

Shear Stress

$$v_u = \frac{|V_u - \phi_v \cdot V_p|}{\phi_v \cdot b_v \cdot d_v}$$ $v_u = 0.158 \cdot ksi$ *(AASHTO LRFD Eq. 5.8.2.9-1)*

$0.125 \cdot f_c = 0.450 \cdot ksi$

if $v_u < 0.125 \cdot f_c$ , $s_{max}$ = minimum of: *(AASHTO LRFD Eq. 5.8.2.7-1)*

$0.8 \cdot d_v = 64.46 \cdot in$

& $24in$

if $v_u \geq 0.125 \cdot f_c$ , $s_{max}$ = minimum of: *(AASHTO LRFD Eq. 5.8.2.7-2)*

$0.4 \cdot d_v = 32.23 \cdot in$

& $12in$

Since $v_u < 0.125*f_c$, $s_{max} = 24.00 \cdot in$

TxDOT limits the maximum transverse reinforcement spacing to 12", therefore: *(BDM-LRFD, Ch. 4, Sect. 4, Detailing)*

$s_{max} = 12.00 \cdot in$

$s_{bar\_S} = 8.50 \cdot in$ < $s_{max}$ SpacingCheck = "OK!"

**Hanger Reinforcement Summary:** Use double #6 stirrups @ 8.5" maximum spacing

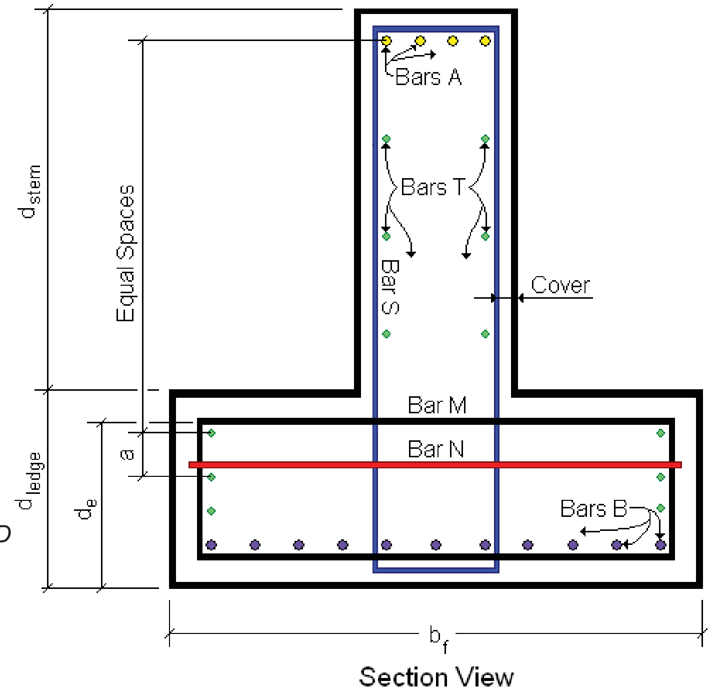
## Vertical End Reinforcement (Bars C) *(BDM-LRFD, Ch. 4, Sect. 5, Detailing)*

Extra vertical reinforcing across end surfaces of the stem is provided to resist cracking which has been observed in existing bridges. *(BDM-LRFD, Ch. 4, Sect. 5, Detailing)* We will place #5 bars at approximately 6 in spacing. *(TxSP)* See the Bent Cap Details in the Appendices for detail of Bar C.

Use 6~#5 bars evenly spaced across each end of the stem

## Skin Reinforcement (Bars T)

Try 7~#6 bars in stem and 3~#6 bars in Ledge on each side




$A_{bar\_T} = 0.44 \cdot in^2$

$NoTBarsStem = 7$

$NoTBarsLedge = 3$

"a" must be within $^2/_3$ of $d_e$

*(AASHTO LRFD 5.13.2.4.1)*

$\frac{2}{3} \cdot d_e = 17.00 \cdot in$

TxDOT typically uses: $a = 6in$ *(TxSP)*

### Required Area of Skin Reinforcement

$A_{sk\_Req} = 0.012 \cdot (d - 30)$ *(AASHTO LRFD Eq. 5.7.3.4-2)*

$A_{sk\_Req} = 0.62 \cdot \frac{in^2}{ft}$

*$A_{sk}$ need not be greater than one quarter of the main reinforcing ($A_s$/4) per side face within d/2 of the main reinforcing. (AASHTO LRFD Eq. 5.7.3.4)*

$A_{sk\_max}$ = maximum of:

$$\frac{A_{bar\_A} \cdot BarANo}{4} \div \frac{d_{s\_neg}}{2} = 0.57 \cdot \frac{in^2}{ft}$$

$$\frac{A_{bar\_B} \cdot BarBNo}{4} \div \frac{d_{s\_pos}}{2} = 1.26 \frac{1}{ft} \cdot in^2$$

$A_{sk\_max} = 1.26 \cdot \frac{in^2}{ft}$

$A_{skReq}$ = minimum of:

$$A_{sk\_Req} = 0.62 \cdot \frac{in^2}{ft}$$

$$A_{sk\_max} = 1.26 \frac{1}{ft} \cdot in^2$$

$A_{skReq} = 0.62 \cdot \frac{in^2}{ft}$

## Skin Reinforcement (Con't) (Bars T)

### Required Spacing of Skin Reinforcement

*(AASHTO LRFD 5.7.3.4)*

$s_{req}$ = minimum of:

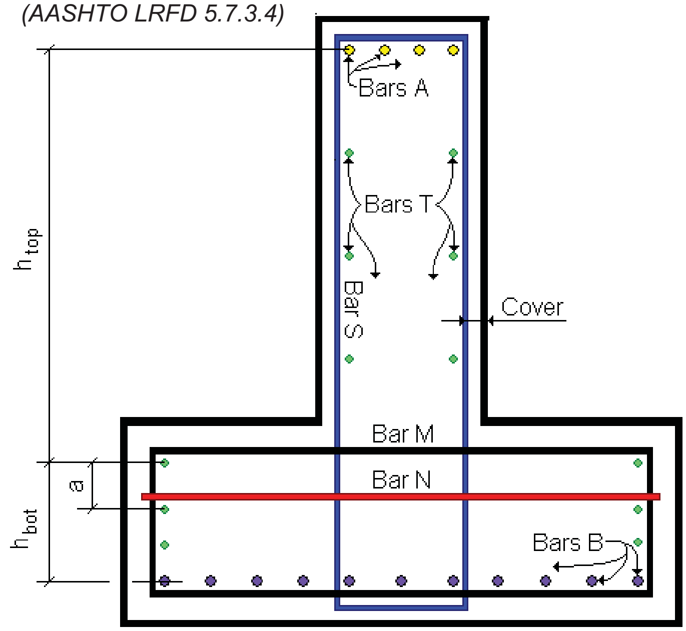
$$\frac{A_{bar\_T}}{A_{skReq}} = 8.56 \cdot in$$

$$\frac{d_{s\_neg}}{6} = 13.57 \cdot in$$

$$\frac{d_{s\_pos}}{6} = 13.57 \cdot in$$

& 12in

$s_{req} = 8.56 \cdot in$




Section View

### Actual Spacing of Skin Reinforcement

Check T bars Spacing in Stem:

$$h_{top} = d_{stem} - \left(cover + \frac{d_{bar\_S}}{2} + \frac{d_{bar\_A}}{2}\right) + \left(cover + \frac{d_{bar\_M}}{2} + \frac{d_{bar\_T}}{2}\right)$$

*"cover" is measured to center of shear reinforcement.*

$h_{top} = 56.67 \cdot in$

$$s_{skStem} = \frac{h_{top}}{NoTBarsStem + 1}$$

$s_{skStem} = 7.08 \cdot in$

$s_{req} = 8.56 \cdot in$ > $s_{skStem}$ SkinSpacing = "OK!"

Check T bars Spacing in Ledge:

$$h_{bot} = d_{ledge} - \left(cover + \frac{d_{bar\_M}}{2} + \frac{d_{bar\_T}}{2}\right) - \left(cover + \frac{d_{bar\_S}}{2} + \frac{d_{bar\_B}}{2}\right)$$

*"cover" is measured to center of shear reinforcement.*

$h_{bot} = 21.17 \cdot in$

$$s_{skLedge} = \frac{h_{bot} - a}{NoTBarsLedge - 1}$$

$s_{skLedge} = 7.58 \cdot in$

$s_{req} = 8.56 \cdot in$ > $s_{skLedge}$ SkinSpacing = "OK!"

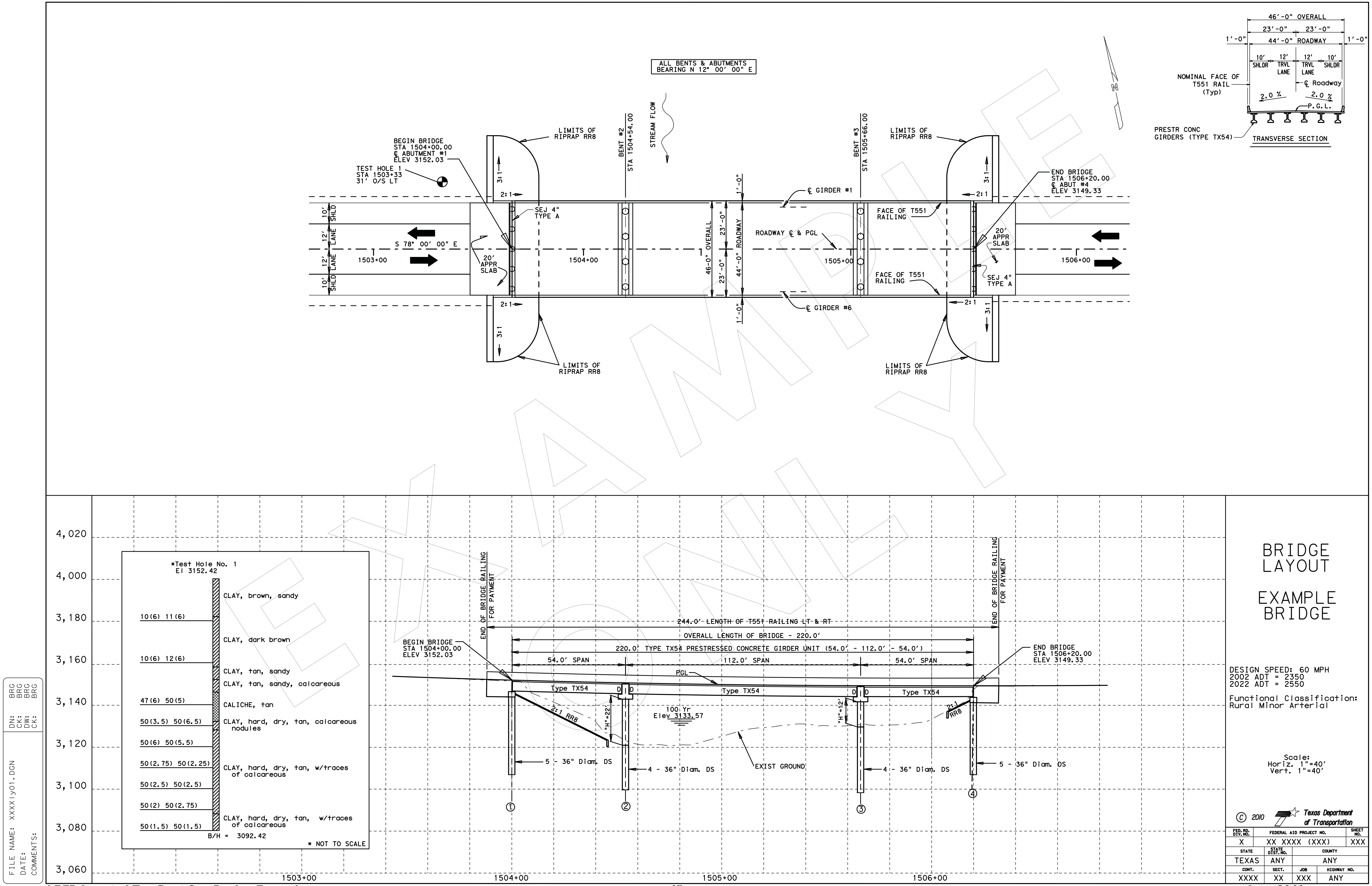
Check if "a" dimension is less than or equal to $s_{req}$:

$a = 6.00 \cdot in$ < $s_{req} = 8.56 \cdot in$ SkinSpacing = "OK!"

## Skin Reinforcement Summary: Use 7~#6 bars in stem and 3~#6 bars in Ledge on each side

*See the Bent Cap Detail Sheet in the Appendices for the resulting design of all the preceding calculations.*

# Appendices



ALL BENTS & ABUTMENTS BEARING N 12° 00' 00" E
STREAM FLOW
BEGIN BRIDGE STA 1504+00.00 ℄ ABUTMENT #1 ELEV 3152.03
TEST HOLE 1 STA 1503+33 31' O/S LT
LIMITS OF RIPRAP RR8
BENT #2 STA 1504+54.00
BENT #3 STA 1505+66.00
END BRIDGE STA 1506+20.00 ℄ ABUT #4 ELEV 3149.33
℄ GIRDER #1
℄ GIRDER #6
SEJ 4" TYPE A
20' APPR SLAB
S 78° 00' 00" E
1503+00
1504+00
1505+00
1506+00
ROADWAY ℄ & PGL
FACE OF T551 RAILING
46'-0" OVERALL
23'-0"
44'-0" ROADWAY
1'-0"
10' SHLD
12' LANE
2:1
3:1
46'-0" OVERALL
23'-0" 23'-0"
1'-0" 44'-0" ROADWAY 1'-0"
10' SHLDR 12' TRVL LANE 12' TRVL LANE 10' SHLDR
NOMINAL FACE OF T551 RAIL (Typ)
℄ Roadway
2.0 % 2.0 %
P.G.L.
PRESTR CONC GIRDERS (TYPE TX54)
TRANSVERSE SECTION
*Test Hole No. 1
El 3152.42
CLAY, brown, sandy
10(6) 11(6)
CLAY, dark brown
10(6) 12(6)
CLAY, tan, sandy
CLAY, tan, sandy, calcareous
47(6) 50(5)
CALICHE, tan
50(3.5) 50(6.5)
CLAY, hard, dry, tan, calcareous nodules
50(6) 50(5.5)
50(2.75) 50(2.25)
CLAY, hard, dry, tan, w/traces of calcareous
50(2.5) 50(2.5)
50(2) 50(2.75)
50(1.5) 50(1.5)
CLAY, hard, dry, tan, w/traces of calcareous
B/H = 3092.42
* NOT TO SCALE
4,020
4,000
3,180
3,160
3,140
3,120
3,100
3,080
3,060
END OF BRIDGE RAILING FOR PAYMENT
244.0' LENGTH OF T551 RAILING LT & RT
OVERALL LENGTH OF BRIDGE - 220.0'
220.0' TYPE TX54 PRESTRESSED CONCRETE GIRDER UNIT (54.0' - 112.0' - 54.0')
54.0' SPAN
112.0' SPAN
54.0' SPAN
BEGIN BRIDGE STA 1504+00.00 ELEV 3152.03
END BRIDGE STA 1506+20.00 ELEV 3149.33
PGL
Type TX54
2:1 RR8
"H"=22'
"H"=12'
100 Yr Elev 3133.57
EXIST GROUND
5 - 36" Diam. DS
4 - 36" Diam. DS
1
2
3
4
1503+00
1504+00
1505+00
1506+00
BRIDGE LAYOUT
EXAMPLE BRIDGE
DESIGN SPEED: 60 MPH
2002 ADT = 2350
2022 ADT = 2550
Functional Classification: Rural Minor Arterial
Scale: Horiz. 1"=40' Vert. 1"=40'
© 2010 Texas Department of Transportation
FED. RD. DIV. NO. | FEDERAL AID PROJECT NO. | SHEET NO.
X | XX XXXX (XXX) | XXX
STATE | STATE DIST. NO. | COUNTY
TEXAS | ANY | ANY
CONT. | SECT. | JOB | HIGHWAY NO.
XXXX | XX | XXX | ANY
DN: BRG CK: BRG DW: BRG CK: BRG
FILE NAME: XXXXlyO1.DGN
DATE:
COMMENTS:

```
00001  ___County____  Highwy  Pro#  XXXX-XX-XXX  BRG               Comment
CAP18 Version 6.10 Inverted Tee Cap Design Example, Skew = 0.00
    1 E   (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
Table 1                                         16                        0.0
Table 2           92 5.000E-01        20    2   70    1    3    1.25     1.75
     1.50          3  1.2       1.0       0.85      0.65      0.65
Table 3            3    6    4   11    8
  (Lane Left)      2   32   60
  (Lane Right)    32   60   90
  (Stringers)      6   22   38   54   70   86
  (Supports)      10   34   58   82
  (Mom CP)         6   10   22   34   38   46   54   58   70   82
  (Mom CP)        86
  (Shear CP)       8   12   32   36   56   60   80   84
Table 4 (Cap)      2   90      6.990E+07            -2.485
(DL Span1, Bm1)    6    6                           -50.17              -5.04
(DL Span1, Bm2)   22   22                           -50.17              -5.04
(DL Span1, Bm3)   38   38                           -50.17              -5.04
(DL Span1, Bm4)   54   54                           -50.17              -5.04
(DL Span1, Bm5)   70   70                           -50.17              -5.04
(DL Span1, Bm6)   86   86                           -50.17              -5.04
(DL Span2, Bm1)    6    6                           -104.1              -10.5
(DL Span2, Bm2)   22   22                           -104.1              -10.5
(DL Span2, Bm3)   38   38                           -104.1              -10.5
(DL Span2, Bm4)   54   54                           -104.1              -10.5
(DL Span2, Bm5)   70   70                           -104.1              -10.5
(DL Span2, Bm6)   86   86                           -104.1              -10.5
(Dist. Lane Ld)    0   20                                     -4.92
(Conc. Lane Ld)    4    4                                     -21.3
(Conc. Lane Ld)   16   16                                     -21.3
```

```
     PSF                 HIGHWAY  PD-    CONTROL-   CODED
      NO      COUNTY        NO    IPE  SECTION-JOB   BY    DATE
    00001  ___County____  Highwy  Pro#  XXXX-XX-XXX  BRG  APR 22, 2010 Comment

CAP18 Version 6.10 Inverted Tee Cap Design Example, Skew = 0.00
PROB      1   (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)


ENGLISH SYSTEM UNITS

TABLE 1.  CONTROL DATA
                                                     ENVELOPES    TABLE NUMBER
                                                     OF MAXIMUMS   2    3    4
     KEEP FROM PRECEDING PROBLEM (1=YES)                  0        0    0    0
     CARDS INPUT THIS PROBLEM                                                 16

     OPTION TO CLEAR ENVELOPES BEFORE LANE LOADINGS (1=YES)                    0

     OPTION TO OMIT PRINT (-1=TABLE 4A, -2=TABLE 5, -3=BOTH)                   0

     SKEW ANGLE, DEGREES                                                   0.000


TABLE 2.  CONSTANTS

     NUMBER OF INCREMENTS FOR SLAB AND CAP                                    92
     INCREMENT LENGTH, FT                                                  0.500
     NUMBER OF INCREMENTS FOR MOVABLE LOAD                                    20
     START POSITION OF MOVABLE-LOAD STA ZERO                                   2
     STOP POSITION OF MOVABLE-LOAD STA ZERO                                   70
     NUMBER OF INCREMENTS BETWEEN EACH POSITION OF MOVABLE LOAD                1

     ANALYSIS OPTION (1=WORKING STRESS, 2=LOAD FACTOR, 3=BOTH)                 3

     LOAD FACTOR FOR DEAD LOAD                                              1.25
     LOAD FACTOR FOR OVERLAY LOAD                                           1.50
     LOAD FACTOR FOR LIVE LOAD                                              1.75

     MAXIMUM NUMBER OF LANES TO BE LOADED SIMULTANEOUSLY                       3

     LIST OF LOAD COEFFICIENTS CORRESPONDING TO NUMBER OF LANES LOADED
          1              2              3              4              5
        1.200          1.000          0.850
```

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 3. LISTS OF STATIONS

| | NUM OF LANES | NUM OF STRINGERS | NUM OF SUPPORTS | NUM MOM CONTR PTS | NUM SHEAR CONTR PTS |
|---|---|---|---|---|---|
| TOTAL | 3 | 6 | 4 | 11 | 8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LANE LEFT | 2 | 32 | 60 | | | | | | | |
| LANE RIGHT | 32 | 60 | 90 | | | | | | | |
| STRINGERS | 6.0 | 22.0 | 38.0 | 54.0 | 70.0 | 86.0 | | | | |
| SUPPORTS | 10 | 34 | 58 | 82 | | | | | | |
| MOM CONTR | 6 | 10 | 22 | 34 | 38 | 46 | 54 | 58 | 70 | 82 |
| | 86 | | | | | | | | | |
| SHEAR CONTR | 8 | 12 | 32 | 36 | 56 | 60 | 80 | 84 | | |

TABLE 4. STIFFNESS AND LOAD DATA

| FIXED-OR-MOVABLE | | | ------------ FIXED-POSITION DATA ------------ | | | | MOVABLE- |
|---|---|---|---|---|---|---|---|
| STA FROM | STA TO | CONTD IF=1 | CAP BENDING STIFFNESS ( K-FT*FT ) | SIDEWALK, SLAB LOADS ( K ) | STRINGER, CAP LOADS ( K ) | OVERLAY LOADS ( K ) | POSITION SLAB LOADS ( K ) |
| 2 | 90 | 0 | 69900000.000 | 0.000 | -2.485 | 0.000 | 0.000 |
| 6 | 6 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 22 | 22 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 38 | 38 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 54 | 54 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 70 | 70 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 86 | 86 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 |
| 6 | 6 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 22 | 22 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 38 | 38 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 54 | 54 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 70 | 70 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 86 | 86 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 |
| 0 | 20 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -4.920 |
| 4 | 4 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 |
| 16 | 16 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 4A. DEAD LOAD RESULTS ( WORKING STRESS )

| STA | DIST X (FT) | DEFLECTION (FT) | MOMENT (K-FT) | SHEAR (K) |
|---|---|---|---|---|
| -1 | -0.50 | 0.000000 | 0.0 | 0.0 |
| 0 | 0.00 | 0.000000 | 0.0 | 0.0 |
| 1 | 0.50 | -0.000039 | 0.0 | 0.0 |
| 2 | 1.00 | -0.000034 | 0.0 | -0.6 |
| 3 | 1.50 | -0.000029 | -0.6 | -2.5 |
| 4 | 2.00 | -0.000025 | -2.5 | -5.0 |
| 5 | 2.50 | -0.000020 | -5.6 | -7.5 |
| 6 | 3.00 | -0.000015 | -9.9 | -94.8 |
| 7 | 3.50 | -0.000011 | -100.4 | -182.2 |
| 8 | 4.00 | -0.000006 | -192.2 | -184.7 |
| 9 | 4.50 | -0.000003 | -285.2 | -187.2 |
| 10 | 5.00 | 0.000000 | -379.4 | -34.9 |
| 11 | 5.50 | 0.000001 | -320.1 | 117.3 |
| 12 | 6.00 | 0.000001 | -262.0 | 114.9 |
| 13 | 6.50 | 0.000001 | -205.2 | 112.4 |
| 14 | 7.00 | -0.000001 | -149.7 | 109.9 |
| 15 | 7.50 | -0.000003 | -95.4 | 107.4 |
| 16 | 8.00 | -0.000006 | -42.3 | 104.9 |
| 17 | 8.50 | -0.000008 | 9.6 | 102.4 |
| 18 | 9.00 | -0.000011 | 60.1 | 99.9 |
| 19 | 9.50 | -0.000013 | 109.5 | 97.5 |
| 20 | 10.00 | -0.000015 | 157.6 | 95.0 |
| 21 | 10.50 | -0.000016 | 204.5 | 92.5 |
| 22 | 11.00 | -0.000017 | 250.1 | 5.1 |
| 23 | 11.50 | -0.000017 | 209.6 | -82.3 |
| 24 | 12.00 | -0.000016 | 167.8 | -84.8 |
| 25 | 12.50 | -0.000014 | 124.8 | -87.3 |
| 26 | 13.00 | -0.000012 | 80.5 | -89.7 |
| 27 | 13.50 | -0.000010 | 35.0 | -92.2 |
| 28 | 14.00 | -0.000008 | -11.7 | -94.7 |
| 29 | 14.50 | -0.000005 | -59.7 | -97.2 |
| 30 | 15.00 | -0.000003 | -108.9 | -99.7 |
| 31 | 15.50 | -0.000001 | -159.4 | -102.2 |
| 32 | 16.00 | 0.000000 | -211.1 | -104.7 |
| 33 | 16.50 | 0.000000 | -264.0 | -107.1 |
| 34 | 17.00 | 0.000000 | -318.2 | 45.0 |
| 35 | 17.50 | -0.000002 | -219.0 | 197.1 |
| 36 | 18.00 | -0.000004 | -121.1 | 194.7 |
| 37 | 18.50 | -0.000007 | -24.4 | 192.2 |
| 38 | 19.00 | -0.000010 | 71.1 | 104.8 |
| 39 | 19.50 | -0.000012 | 80.4 | 17.4 |
| 40 | 20.00 | -0.000015 | 88.5 | 14.9 |
| 41 | 20.50 | -0.000017 | 95.3 | 12.4 |
| 42 | 21.00 | -0.000019 | 100.9 | 9.9 |
| 43 | 21.50 | -0.000020 | 105.3 | 7.5 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 4A. DEAD LOAD RESULTS ( WORKING STRESS )

| STA | DIST X (FT) | DEFLECTION (FT) | MOMENT (K-FT) | SHEAR (K) |
|---|---|---|---|---|
| 44 | 22.00 | -0.000021 | 108.4 | 5.0 |
| 45 | 22.50 | -0.000021 | 110.2 | 2.5 |
| 46 | 23.00 | -0.000022 | 110.9 | 0.0 |
| 47 | 23.50 | -0.000021 | 110.2 | -2.5 |
| 48 | 24.00 | -0.000021 | 108.4 | -5.0 |
| 49 | 24.50 | -0.000020 | 105.3 | -7.5 |
| 50 | 25.00 | -0.000019 | 100.9 | -9.9 |
| 51 | 25.50 | -0.000017 | 95.3 | -12.4 |
| 52 | 26.00 | -0.000015 | 88.5 | -14.9 |
| 53 | 26.50 | -0.000012 | 80.4 | -17.4 |
| 54 | 27.00 | -0.000010 | 71.1 | -104.8 |
| 55 | 27.50 | -0.000007 | -24.4 | -192.2 |
| 56 | 28.00 | -0.000004 | -121.1 | -194.7 |
| 57 | 28.50 | -0.000002 | -219.0 | -197.1 |
| 58 | 29.00 | 0.000000 | -318.2 | -45.0 |
| 59 | 29.50 | 0.000000 | -264.0 | 107.1 |
| 60 | 30.00 | 0.000000 | -211.1 | 104.7 |
| 61 | 30.50 | -0.000001 | -159.4 | 102.2 |
| 62 | 31.00 | -0.000003 | -108.9 | 99.7 |
| 63 | 31.50 | -0.000005 | -59.7 | 97.2 |
| 64 | 32.00 | -0.000008 | -11.7 | 94.7 |
| 65 | 32.50 | -0.000010 | 35.0 | 92.2 |
| 66 | 33.00 | -0.000012 | 80.5 | 89.7 |
| 67 | 33.50 | -0.000014 | 124.8 | 87.3 |
| 68 | 34.00 | -0.000016 | 167.8 | 84.8 |
| 69 | 34.50 | -0.000017 | 209.6 | 82.3 |
| 70 | 35.00 | -0.000017 | 250.1 | -5.1 |
| 71 | 35.50 | -0.000016 | 204.5 | -92.5 |
| 72 | 36.00 | -0.000015 | 157.6 | -95.0 |
| 73 | 36.50 | -0.000013 | 109.5 | -97.5 |
| 74 | 37.00 | -0.000011 | 60.1 | -99.9 |
| 75 | 37.50 | -0.000008 | 9.6 | -102.4 |
| 76 | 38.00 | -0.000006 | -42.3 | -104.9 |
| 77 | 38.50 | -0.000003 | -95.4 | -107.4 |
| 78 | 39.00 | -0.000001 | -149.7 | -109.9 |
| 79 | 39.50 | 0.000001 | -205.2 | -112.4 |
| 80 | 40.00 | 0.000001 | -262.0 | -114.9 |
| 81 | 40.50 | 0.000001 | -320.1 | -117.3 |
| 82 | 41.00 | 0.000000 | -379.4 | 34.9 |
| 83 | 41.50 | -0.000003 | -285.2 | 187.2 |
| 84 | 42.00 | -0.000006 | -192.2 | 184.7 |
| 85 | 42.50 | -0.000011 | -100.4 | 182.2 |
| 86 | 43.00 | -0.000015 | -9.9 | 94.8 |
| 87 | 43.50 | -0.000020 | -5.6 | 7.5 |
| 88 | 44.00 | -0.000025 | -2.5 | 5.0 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 4A. DEAD LOAD RESULTS ( WORKING STRESS )

| STA | DIST X (FT) | DEFLECTION (FT) | MOMENT (K-FT) | SHEAR (K) |
|---|---|---|---|---|
| 89 | 44.50 | -0.000029 | -0.6 | 2.5 |
| 90 | 45.00 | -0.000034 | 0.0 | 0.6 |
| 91 | 45.50 | -0.000039 | 0.0 | 0.0 |
| 92 | 46.00 | 0.000000 | 0.0 | 0.0 |
| 93 | 46.50 | 0.000000 | 0.0 | 0.0 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY ( WORKING STRESS )
( *--CRITICAL NUMBER OF LANE LOADS)

MOMENT ( FT-K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 6 | -9.9 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | 0.0 | | |
| | | 1 | 0.0 | | | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 10 | -379.4 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -176.2 | 1 | 2 |
| | | 1 | 0.0 | | | 1 | -176.2 | 1 | 2 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 22 | 250.1 | | | | | | | | |
| | | 0 | 202.0 | 0 | 13 | 0 | -33.4 | 2 | 36 |
| | | 1 | 201.2 | 1 | 12 | 1 | -33.4 | 2 | 36 |
| | | 2 | 9.3 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 34 | -318.2 | | | | | | | | |
| | | 0 | 18.7 | 3 | 62 | 0 | -136.3 | 0 | 18 |
| | | 1 | 18.7 | 3 | 62 | 1 | -116.6 | 1 | 12 |
| | | 2 | 0.0 | | | 2 | -84.7 | 2 | 32 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 38 | 71.1 | | | | | | | | |
| | | 0 | 83.6 | 2 | 32 | 0 | -58.8 | 1 | 9 |
| | | 1 | 83.6 | 2 | 32 | 1 | -58.8 | 1 | 9 |
| | | 2 | 3.2 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 46 | 110.9 | | | | | | | | |
| | | 0 | 69.4 | 2 | 36 | 0 | -27.8 | 1 | 9 |
| | | 1 | 69.4 | 2 | 36 | 1 | -27.8 | 1 | 9 |
| | | 2 | 0.0 | | | 2 | -27.8 | 3 | 63 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

MOMENT ( FT-K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 71.1 | | | | | | | | |
| | | 0 | 83.6 | 2 | 40 | 0 | -58.8 | 3 | 63 |
| | | 1 | 83.6 | 2 | 40 | 1 | -58.8 | 3 | 63 |
| | | 2 | 3.2 | 1 | 10 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 58 | -318.2 | | | | | | | | |
| | | 0 | 18.7 | 1 | 9 | 0 | -136.3 | 0 | 54 |
| | | 1 | 18.7 | 1 | 9 | 1 | -116.6 | 3 | 60 |
| | | 2 | 0.0 | | | 2 | -84.7 | 2 | 40 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 70 | 250.1 | | | | | | | | |
| | | 0 | 202.0 | 0 | 59 | 0 | -33.4 | 2 | 36 |
| | | 1 | 201.2 | 3 | 60 | 1 | -33.4 | 2 | 36 |
| | | 2 | 9.3 | 1 | 9 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 82 | -379.4 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -176.3 | 3 | 70 |
| | | 1 | 0.0 | | | 1 | -176.3 | 3 | 70 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 86 | -9.9 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | 0.0 | | |
| | | 1 | 0.0 | | | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

SHEAR ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 8 | -184.7 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -88.1 | 1 | 2 |
| | | 1 | 0.0 | | | 1 | -88.1 | 1 | 2 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 12 | 114.9 | | | | | | | | |
| | | 0 | 44.8 | 1 | 6 | 0 | -5.6 | 2 | 36 |
| | | 1 | 44.8 | 1 | 6 | 1 | -5.6 | 2 | 36 |
| | | 2 | 1.6 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 32 | -104.7 | | | | | | | | |
| | | 0 | 1.6 | 3 | 62 | 0 | -54.6 | 0 | 15 |
| | | 1 | 1.6 | 3 | 62 | 1 | -53.0 | 1 | 12 |
| | | 2 | 0.0 | | | 2 | -11.2 | 2 | 32 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 36 | 194.7 | | | | | | | | |
| | | 0 | 87.6 | 0 | 28 | 0 | -7.8 | 3 | 63 |
| | | 1 | 84.1 | 2 | 32 | 1 | -7.8 | 3 | 63 |
| | | 2 | 30.7 | 1 | 12 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 56 | -194.7 | | | | | | | | |
| | | 0 | 7.8 | 1 | 9 | 0 | -87.6 | 0 | 44 |
| | | 1 | 7.8 | 1 | 9 | 1 | -84.1 | 2 | 40 |
| | | 2 | 0.0 | | | 2 | -30.7 | 3 | 60 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 60 | 104.7 | | | | | | | | |
| | | 0 | 54.6 | 0 | 57 | 0 | -1.6 | 1 | 9 |
| | | 1 | 53.0 | 3 | 60 | 1 | -1.6 | 1 | 9 |
| | | 2 | 11.2 | 2 | 40 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

SHEAR ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 80 | -114.9 | | | | | | | | |
| | | 0 | 5.6 | 2 | 36 | 0 | -44.8 | 3 | 66 |
| | | 1 | 5.6 | 2 | 36 | 1 | -44.8 | 3 | 66 |
| | | 2 | 0.0 | | | 2 | -1.6 | 1 | 9 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 84 | 184.7 | | | | | | | | |
| | | 0 | 88.1 | 3 | 70 | 0 | 0.0 | | |
| | | 1 | 88.1 | 3 | 70 | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

REACTION ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 309.5 | | | | | | | | |
| | | 0 | 127.9 | 1 | 2 | 0 | -5.6 | 2 | 36 |
| | | 1 | 127.9 | 1 | 2 | 1 | -5.6 | 2 | 36 |
| | | 2 | 1.6 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 34 | 309.3 | | | | | | | | |
| | | 0 | 117.1 | 0 | 22 | 0 | -9.3 | 3 | 63 |
| | | 1 | 95.3 | 2 | 32 | 1 | -9.3 | 3 | 63 |
| | | 2 | 83.6 | 1 | 12 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 58 | 309.3 | | | | | | | | |
| | | 0 | 117.1 | 0 | 50 | 0 | -9.3 | 1 | 9 |
| | | 1 | 95.3 | 2 | 40 | 1 | -9.3 | 1 | 9 |
| | | 2 | 83.6 | 3 | 60 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 82 | 309.5 | | | | | | | | |
| | | 0 | 127.9 | 3 | 70 | 0 | -5.6 | 2 | 36 |
| | | 1 | 127.9 | 3 | 70 | 1 | -5.6 | 2 | 36 |
| | | 2 | 1.6 | 1 | 9 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( WORKING STRESS )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| -1 | -0.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 1.00 | 0.0 | 0.0 | -0.6 | -0.6 |
| 3 | 1.50 | -0.6 | -0.6 | -2.5 | -2.5 |
| 4 | 2.00 | -2.5 | -2.5 | -5.0 | -5.0 |
| 5 | 2.50 | -5.6 | -5.6 | -7.5 | -7.5 |
| 6 | 3.00 | -9.9 | -9.9 | -94.8 | -147.7 |
| 7 | 3.50 | -100.4 | -153.3 | -182.2 | -288.0 |
| 8 | 4.00 | -192.2 | -297.9 | -184.7 | -290.5 |
| 9 | 4.50 | -285.2 | -443.8 | -187.2 | -293.0 |
| 10 | 5.00 | -379.4 | -590.9 | -18.0 | -64.0 |
| 11 | 5.50 | -307.0 | -507.7 | 171.1 | 110.7 |
| 12 | 6.00 | -231.2 | -425.8 | 168.6 | 108.2 |
| 13 | 6.50 | -156.0 | -345.2 | 166.2 | 105.7 |
| 14 | 7.00 | -82.0 | -265.8 | 163.7 | 103.2 |
| 15 | 7.50 | -9.0 | -187.6 | 161.2 | 100.7 |
| 16 | 8.00 | 64.1 | -110.7 | 158.7 | 98.2 |
| 17 | 8.50 | 136.9 | -35.0 | 156.2 | 95.8 |
| 18 | 9.00 | 209.5 | 33.5 | 153.7 | 93.3 |
| 19 | 9.50 | 281.3 | 79.5 | 151.2 | 90.8 |
| 20 | 10.00 | 352.6 | 124.2 | 148.8 | 88.3 |
| 21 | 10.50 | 422.8 | 167.8 | 146.3 | 85.8 |
| 22 | 11.00 | 492.5 | 210.1 | 21.1 | -8.0 |
| 23 | 11.50 | 419.6 | 165.8 | -80.4 | -147.8 |
| 24 | 12.00 | 345.7 | 120.2 | -82.9 | -150.3 |
| 25 | 12.50 | 270.9 | 73.1 | -85.4 | -152.8 |
| 26 | 13.00 | 195.0 | 24.6 | -87.9 | -155.3 |
| 27 | 13.50 | 118.7 | -25.5 | -90.4 | -157.8 |
| 28 | 14.00 | 47.5 | -76.9 | -92.9 | -160.3 |
| 29 | 14.50 | -23.4 | -129.5 | -95.3 | -162.8 |
| 30 | 15.00 | -90.2 | -183.8 | -97.8 | -165.2 |
| 31 | 15.50 | -139.8 | -264.5 | -100.3 | -167.7 |
| 32 | 16.00 | -190.5 | -348.2 | -102.8 | -170.2 |
| 33 | 16.50 | -242.5 | -433.2 | -105.3 | -172.7 |
| 34 | 17.00 | -295.8 | -519.5 | 88.8 | 27.4 |
| 35 | 17.50 | -201.3 | -362.9 | 311.9 | 187.8 |
| 36 | 18.00 | -107.9 | -225.2 | 309.5 | 185.4 |
| 37 | 18.50 | 26.3 | -109.4 | 307.0 | 182.9 |
| 38 | 19.00 | 171.4 | 0.5 | 163.2 | 95.5 |
| 39 | 19.50 | 177.7 | 14.5 | 26.7 | 8.1 |
| 40 | 20.00 | 183.2 | 27.2 | 24.2 | 5.6 |
| 41 | 20.50 | 187.6 | 38.7 | 21.7 | 3.1 |
| 42 | 21.00 | 191.1 | 45.3 | 19.2 | 0.6 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( WORKING STRESS )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| 43 | 21.50 | 193.3 | 49.6 | 16.8 | -1.8 |
| 44 | 22.00 | 194.4 | 52.7 | 14.3 | -4.3 |
| 45 | 22.50 | 194.2 | 54.6 | 11.8 | -6.8 |
| 46 | 23.00 | 194.1 | 55.2 | 9.3 | -9.3 |
| 47 | 23.50 | 194.2 | 54.6 | 6.8 | -11.8 |
| 48 | 24.00 | 194.4 | 52.7 | 4.3 | -14.3 |
| 49 | 24.50 | 193.3 | 49.6 | 1.8 | -16.8 |
| 50 | 25.00 | 191.1 | 45.3 | -0.6 | -19.2 |
| 51 | 25.50 | 187.6 | 38.7 | -3.1 | -21.7 |
| 52 | 26.00 | 183.2 | 27.2 | -5.6 | -24.2 |
| 53 | 26.50 | 177.7 | 14.5 | -8.1 | -26.7 |
| 54 | 27.00 | 171.4 | 0.5 | -95.5 | -163.2 |
| 55 | 27.50 | 26.3 | -109.4 | -182.9 | -307.0 |
| 56 | 28.00 | -107.9 | -225.2 | -185.4 | -309.5 |
| 57 | 28.50 | -201.3 | -362.9 | -187.8 | -311.9 |
| 58 | 29.00 | -295.8 | -519.5 | -27.4 | -88.8 |
| 59 | 29.50 | -242.5 | -433.2 | 172.7 | 105.3 |
| 60 | 30.00 | -190.5 | -348.2 | 170.2 | 102.8 |
| 61 | 30.50 | -139.8 | -264.5 | 167.7 | 100.3 |
| 62 | 31.00 | -90.2 | -183.8 | 165.2 | 97.8 |
| 63 | 31.50 | -23.4 | -129.5 | 162.8 | 95.3 |
| 64 | 32.00 | 47.5 | -76.9 | 160.3 | 92.9 |
| 65 | 32.50 | 118.7 | -25.5 | 157.8 | 90.4 |
| 66 | 33.00 | 195.0 | 24.6 | 155.3 | 87.9 |
| 67 | 33.50 | 270.9 | 73.1 | 152.8 | 85.4 |
| 68 | 34.00 | 345.7 | 120.2 | 150.3 | 82.9 |
| 69 | 34.50 | 419.6 | 165.8 | 147.8 | 80.4 |
| 70 | 35.00 | 492.5 | 210.1 | 8.0 | -21.1 |
| 71 | 35.50 | 422.8 | 167.8 | -85.8 | -146.3 |
| 72 | 36.00 | 352.6 | 124.2 | -88.3 | -148.8 |
| 73 | 36.50 | 281.3 | 79.5 | -90.8 | -151.2 |
| 74 | 37.00 | 209.5 | 33.5 | -93.3 | -153.7 |
| 75 | 37.50 | 136.9 | -35.0 | -95.8 | -156.2 |
| 76 | 38.00 | 64.1 | -110.7 | -98.2 | -158.7 |
| 77 | 38.50 | -9.0 | -187.6 | -100.7 | -161.2 |
| 78 | 39.00 | -82.0 | -265.8 | -103.2 | -163.7 |
| 79 | 39.50 | -156.0 | -345.2 | -105.7 | -166.2 |
| 80 | 40.00 | -231.2 | -425.8 | -108.2 | -168.6 |
| 81 | 40.50 | -307.0 | -507.7 | -110.7 | -171.1 |
| 82 | 41.00 | -379.4 | -590.9 | 64.0 | 18.0 |
| 83 | 41.50 | -285.2 | -443.8 | 293.0 | 187.2 |
| 84 | 42.00 | -192.2 | -297.9 | 290.5 | 184.7 |
| 85 | 42.50 | -100.4 | -153.3 | 288.0 | 182.2 |
| 86 | 43.00 | -9.9 | -9.9 | 147.7 | 94.8 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( WORKING STRESS )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| 87 | 43.50 | -5.6 | -5.6 | 7.5 | 7.5 |
| 88 | 44.00 | -2.5 | -2.5 | 5.0 | 5.0 |
| 89 | 44.50 | -0.6 | -0.6 | 2.5 | 2.5 |
| 90 | 45.00 | 0.0 | 0.0 | 0.6 | 0.6 |
| 91 | 45.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 92 | 46.00 | 0.0 | 0.0 | 0.0 | 0.0 |
| 93 | 46.50 | 0.0 | 0.0 | 0.0 | 0.0 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 7. MAXIMUM SUPPORT REACTIONS ( WORKING STRESS )

| STA | DIST X ( FT ) | MAX + REACT ( K ) | MAX - REACT ( K ) |
|---|---|---|---|
| 10 | 5.00 | 463.0 | 302.8 |
| 34 | 17.00 | 488.2 | 298.1 |
| 58 | 29.00 | 488.2 | 298.1 |
| 82 | 41.00 | 463.0 | 302.8 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY ( LOAD FACTOR)
( *--CRITICAL NUMBER OF LANE LOADS)

MOMENT ( FT-K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 6 | -12.4 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | 0.0 | | |
| | | 1 | 0.0 | | | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 10 | -482.0 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -308.4 | 1 | 2 |
| | | 1 | 0.0 | | | 1 | -308.4 | 1 | 2 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 22 | 317.5 | | | | | | | | |
| | | 0 | 353.5 | 0 | 13 | 0 | -58.4 | 2 | 36 |
| | | 1 | 352.1 | 1 | 12 | 1 | -58.4 | 2 | 36 |
| | | 2 | 16.3 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 34 | -403.6 | | | | | | | | |
| | | 0 | 32.7 | 3 | 62 | 0 | -238.5 | 0 | 18 |
| | | 1 | 32.7 | 3 | 62 | 1 | -204.0 | 1 | 12 |
| | | 2 | 0.0 | | | 2 | -148.2 | 2 | 32 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 38 | 90.8 | | | | | | | | |
| | | 0 | 146.3 | 2 | 32 | 0 | -102.9 | 1 | 9 |
| | | 1 | 146.3 | 2 | 32 | 1 | -102.9 | 1 | 9 |
| | | 2 | 5.6 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 46 | 140.5 | | | | | | | | |
| | | 0 | 121.4 | 2 | 36 | 0 | -48.7 | 1 | 9 |
| | | 1 | 121.4 | 2 | 36 | 1 | -48.7 | 1 | 9 |
| | | 2 | 0.0 | | | 2 | -48.7 | 3 | 63 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

MOMENT ( FT-K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 90.8 | | | | | | | | |
| | | 0 | 146.3 | 2 | 40 | 0 | -102.9 | 3 | 63 |
| | | 1 | 146.3 | 2 | 40 | 1 | -102.9 | 3 | 63 |
| | | 2 | 5.6 | 1 | 10 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 58 | -403.6 | | | | | | | | |
| | | 0 | 32.7 | 1 | 9 | 0 | -238.5 | 0 | 54 |
| | | 1 | 32.7 | 1 | 9 | 1 | -204.0 | 3 | 60 |
| | | 2 | 0.0 | | | 2 | -148.2 | 2 | 40 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 70 | 317.5 | | | | | | | | |
| | | 0 | 353.5 | 0 | 59 | 0 | -58.4 | 2 | 36 |
| | | 1 | 352.1 | 3 | 60 | 1 | -58.4 | 2 | 36 |
| | | 2 | 16.3 | 1 | 9 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 82 | -482.0 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -308.4 | 3 | 70 |
| | | 1 | 0.0 | | | 1 | -308.4 | 3 | 70 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 86 | -12.4 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | 0.0 | | |
| | | 1 | 0.0 | | | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

SHEAR ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 8 | -234.8 | | | | | | | | |
| | | 0 | 0.0 | | | 0 | -154.2 | 1 | 2 |
| | | 1 | 0.0 | | | 1 | -154.2 | 1 | 2 |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 12 | 145.7 | | | | | | | | |
| | | 0 | 78.4 | 1 | 6 | 0 | -9.7 | 2 | 36 |
| | | 1 | 78.4 | 1 | 6 | 1 | -9.7 | 2 | 36 |
| | | 2 | 2.7 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 32 | -132.6 | | | | | | | | |
| | | 0 | 2.7 | 3 | 62 | 0 | -95.6 | 0 | 15 |
| | | 1 | 2.7 | 3 | 62 | 1 | -92.7 | 1 | 12 |
| | | 2 | 0.0 | | | 2 | -19.5 | 2 | 32 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 36 | 247.2 | | | | | | | | |
| | | 0 | 153.2 | 0 | 28 | 0 | -13.6 | 3 | 63 |
| | | 1 | 147.2 | 2 | 32 | 1 | -13.6 | 3 | 63 |
| | | 2 | 53.7 | 1 | 12 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 56 | -247.2 | | | | | | | | |
| | | 0 | 13.6 | 1 | 9 | 0 | -153.2 | 0 | 44 |
| | | 1 | 13.6 | 1 | 9 | 1 | -147.2 | 2 | 40 |
| | | 2 | 0.0 | | | 2 | -53.7 | 3 | 60 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 2* | | | |
| 60 | 132.6 | | | | | | | | |
| | | 0 | 95.6 | 0 | 57 | 0 | -2.7 | 1 | 9 |
| | | 1 | 92.7 | 3 | 60 | 1 | -2.7 | 1 | 9 |
| | | 2 | 19.5 | 2 | 40 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

SHEAR ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 80 | -145.7 | | | | | | | | |
| | | 0 | 9.7 | 2 | 36 | 0 | -78.4 | 3 | 66 |
| | | 1 | 9.7 | 2 | 36 | 1 | -78.4 | 3 | 66 |
| | | 2 | 0.0 | | | 2 | -2.7 | 1 | 9 |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 84 | 234.8 | | | | | | | | |
| | | 0 | 154.2 | 3 | 70 | 0 | 0.0 | | |
| | | 1 | 154.2 | 3 | 70 | 1 | 0.0 | | |
| | | 2 | 0.0 | | | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

REACTION ( K )

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUM | LOAD LANE | AT STA | LANE ORDER | NEGATIVE MAXIMUM | LOAD LANE | AT STA |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 392.9 | | | | | | | | |
| | | 0 | 223.8 | 1 | 2 | 0 | -9.7 | 2 | 36 |
| | | 1 | 223.8 | 1 | 2 | 1 | -9.7 | 2 | 36 |
| | | 2 | 2.7 | 3 | 62 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |
| 34 | 392.2 | | | | | | | | |
| | | 0 | 205.0 | 0 | 22 | 0 | -16.3 | 3 | 63 |
| | | 1 | 166.8 | 2 | 32 | 1 | -16.3 | 3 | 63 |
| | | 2 | 146.3 | 1 | 12 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 58 | 392.2 | | | | | | | | |
| | | 0 | 205.0 | 0 | 50 | 0 | -16.3 | 1 | 9 |
| | | 1 | 166.8 | 2 | 40 | 1 | -16.3 | 1 | 9 |
| | | 2 | 146.3 | 3 | 60 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 2* | | | | 0* | | | |
| 82 | 392.9 | | | | | | | | |
| | | 0 | 223.8 | 3 | 70 | 0 | -9.7 | 2 | 36 |
| | | 1 | 223.8 | 3 | 70 | 1 | -9.7 | 2 | 36 |
| | | 2 | 2.7 | 1 | 9 | 2 | 0.0 | | |
| | | 3 | 0.0 | | | 3 | 0.0 | | |
| | | 0* | | | | 0* | | | |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( LOAD FACTOR )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| -1 | -0.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | 0.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 1.00 | 0.0 | 0.0 | -0.8 | -0.8 |
| 3 | 1.50 | -0.8 | -0.8 | -3.1 | -3.1 |
| 4 | 2.00 | -3.1 | -3.1 | -6.2 | -6.2 |
| 5 | 2.50 | -7.0 | -7.0 | -9.3 | -9.3 |
| 6 | 3.00 | -12.4 | -12.4 | -120.5 | -213.0 |
| 7 | 3.50 | -127.5 | -220.0 | -231.7 | -416.7 |
| 8 | 4.00 | -244.1 | -429.2 | -234.8 | -419.8 |
| 9 | 4.50 | -362.3 | -639.9 | -237.9 | -423.0 |
| 10 | 5.00 | -482.0 | -852.1 | -15.0 | -95.4 |
| 11 | 5.50 | -383.9 | -735.2 | 242.9 | 137.1 |
| 12 | 6.00 | -279.2 | -619.9 | 239.8 | 134.0 |
| 13 | 6.50 | -174.9 | -506.1 | 236.7 | 130.9 |
| 14 | 7.00 | -72.2 | -393.8 | 233.6 | 127.8 |
| 15 | 7.50 | 29.4 | -283.2 | 230.5 | 124.7 |
| 16 | 8.00 | 131.8 | -174.0 | 227.4 | 121.6 |
| 17 | 8.50 | 234.4 | -66.4 | 224.3 | 118.5 |
| 18 | 9.00 | 337.2 | 29.1 | 221.2 | 115.4 |
| 19 | 9.50 | 439.2 | 86.0 | 218.1 | 112.2 |
| 20 | 10.00 | 540.9 | 141.4 | 215.0 | 109.1 |
| 21 | 10.50 | 641.5 | 195.2 | 211.8 | 106.0 |
| 22 | 11.00 | 741.7 | 247.4 | 34.5 | -16.5 |
| 23 | 11.50 | 633.5 | 189.4 | -101.4 | -219.4 |
| 24 | 12.00 | 524.1 | 129.6 | -104.5 | -222.5 |
| 25 | 12.50 | 413.8 | 67.7 | -107.6 | -225.6 |
| 26 | 13.00 | 302.3 | 4.0 | -110.7 | -228.7 |
| 27 | 13.50 | 190.6 | -61.8 | -113.8 | -231.8 |
| 28 | 14.00 | 88.6 | -129.2 | -116.9 | -234.9 |
| 29 | 14.50 | -12.5 | -198.1 | -120.0 | -238.0 |
| 30 | 15.00 | -105.7 | -269.4 | -123.1 | -241.1 |
| 31 | 15.50 | -168.0 | -386.3 | -126.2 | -244.2 |
| 32 | 16.00 | -231.9 | -507.9 | -129.3 | -247.3 |
| 33 | 16.50 | -297.4 | -631.1 | -132.4 | -250.4 |
| 34 | 17.00 | -364.4 | -755.8 | 133.9 | 26.5 |
| 35 | 17.50 | -246.6 | -529.4 | 451.2 | 234.0 |
| → 36 | 18.00 | -130.3 | -335.6 | 448.1 | 230.9 |
| 37 | 18.50 | 58.2 | -179.2 | 445.0 | 227.8 |
| 38 | 19.00 | 266.4 | -32.7 | 235.2 | 116.6 |
| 39 | 19.50 | 272.8 | -12.9 | 38.0 | 5.5 |
| 40 | 20.00 | 278.2 | 5.3 | 34.9 | 2.4 |
| 41 | 20.50 | 282.6 | 22.0 | 31.8 | -0.7 |
| 42 | 21.00 | 285.9 | 30.7 | 28.7 | -3.9 |
| 43 | 21.50 | 287.7 | 36.1 | 25.6 | -7.0 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( LOAD FACTOR )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| 44 | 22.00 | 287.9 | 40.0 | 22.5 | -10.1 |
| 45 | 22.50 | 286.6 | 42.4 | 19.4 | -13.2 |
| 46 | 23.00 | 286.2 | 43.1 | 16.3 | -16.3 |
| 47 | 23.50 | 286.6 | 42.4 | 13.2 | -19.4 |
| 48 | 24.00 | 287.9 | 40.0 | 10.1 | -22.5 |
| 49 | 24.50 | 287.7 | 36.1 | 7.0 | -25.6 |
| 50 | 25.00 | 285.9 | 30.7 | 3.9 | -28.7 |
| 51 | 25.50 | 282.6 | 22.0 | 0.7 | -31.8 |
| 52 | 26.00 | 278.2 | 5.3 | -2.4 | -34.9 |
| 53 | 26.50 | 272.8 | -12.9 | -5.5 | -38.0 |
| 54 | 27.00 | 266.4 | -32.7 | -116.6 | -235.2 |
| 55 | 27.50 | 58.2 | -179.2 | -227.8 | -445.0 |
| 56 | 28.00 | -130.3 | -335.6 | -230.9 | -448.1 |
| 57 | 28.50 | -246.6 | -529.4 | -234.0 | -451.2 |
| 58 | 29.00 | -364.4 | -755.8 | -26.5 | -133.9 |
| 59 | 29.50 | -297.4 | -631.1 | 250.4 | 132.4 |
| 60 | 30.00 | -231.9 | -507.9 | 247.3 | 129.3 |
| 61 | 30.50 | -168.0 | -386.3 | 244.2 | 126.2 |
| 62 | 31.00 | -105.7 | -269.4 | 241.1 | 123.1 |
| 63 | 31.50 | -12.5 | -198.1 | 238.0 | 120.0 |
| 64 | 32.00 | 88.6 | -129.2 | 234.9 | 116.9 |
| 65 | 32.50 | 190.6 | -61.8 | 231.8 | 113.8 |
| 66 | 33.00 | 302.3 | 4.0 | 228.7 | 110.7 |
| 67 | 33.50 | 413.8 | 67.7 | 225.6 | 107.6 |
| 68 | 34.00 | 524.1 | 129.6 | 222.5 | 104.5 |
| 69 | 34.50 | 633.5 | 189.4 | 219.4 | 101.4 |
| 70 | 35.00 | 741.7 | 247.4 | 16.5 | -34.5 |
| 71 | 35.50 | 641.5 | 195.2 | -106.0 | -211.8 |
| 72 | 36.00 | 540.9 | 141.4 | -109.1 | -215.0 |
| 73 | 36.50 | 439.2 | 86.0 | -112.2 | -218.1 |
| 74 | 37.00 | 337.2 | 29.1 | -115.4 | -221.2 |
| 75 | 37.50 | 234.4 | -66.4 | -118.5 | -224.3 |
| 76 | 38.00 | 131.8 | -174.0 | -121.6 | -227.4 |
| 77 | 38.50 | 29.4 | -283.2 | -124.7 | -230.5 |
| 78 | 39.00 | -72.2 | -393.8 | -127.8 | -233.6 |
| 79 | 39.50 | -174.9 | -506.1 | -130.9 | -236.7 |
| 80 | 40.00 | -279.2 | -619.9 | -134.0 | -239.8 |
| 81 | 40.50 | -383.9 | -735.2 | -137.1 | -242.9 |
| 82 | 41.00 | -482.0 | -852.1 | 95.4 | 15.0 |
| 83 | 41.50 | -362.3 | -639.9 | 423.0 | 237.9 |
| 84 | 42.00 | -244.1 | -429.2 | 419.8 | 234.8 |
| 85 | 42.50 | -127.5 | -220.0 | 416.7 | 231.7 |
| 86 | 43.00 | -12.4 | -12.4 | 213.0 | 120.5 |
| 87 | 43.50 | -7.0 | -7.0 | 9.3 | 9.3 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES ( LOAD FACTOR )

| STA | DIST X ( FT ) | MAX + MOM ( FT-K ) | MAX - MOM ( FT-K ) | MAX + SHEAR ( K ) | MAX - SHEAR ( K ) |
|---|---|---|---|---|---|
| 88 | 44.00 | -3.1 | -3.1 | 6.2 | 6.2 |
| 89 | 44.50 | -0.8 | -0.8 | 3.1 | 3.1 |
| 90 | 45.00 | 0.0 | 0.0 | 0.8 | 0.8 |
| 91 | 45.50 | 0.0 | 0.0 | 0.0 | 0.0 |
| 92 | 46.00 | 0.0 | 0.0 | 0.0 | 0.0 |
| 93 | 46.50 | 0.0 | 0.0 | 0.0 | 0.0 |

PROB 1 (Spans 54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay)
(CONTINUED)

TABLE 7. MAXIMUM SUPPORT REACTIONS ( LOAD FACTOR )

| STA | DIST X ( FT ) | MAX + REACT ( K ) | MAX - REACT ( K ) |
|---|---|---|---|
| 10 | 5.00 | 661.4 | 381.2 |
| 34 | 17.00 | 705.3 | 372.7 |
| 58 | 29.00 | 705.3 | 372.7 |
| 82 | 41.00 | 661.4 | 381.2 |

## LRFD Live Load Distribution Factors*

Live Load Distribution Factors are calculated according to AASHTO LRFD Bridge Design Specifications, 4th Edition (2007 with no interim revisions) as prescribed by TxDOT policies (LRFD Design Manual July 2008) and practices. The Lever Rule is used when outside the Range of Applicability. The Range of Applicability for the Skew Correction Factors is ignored.

**INPUT:**

| | | |
|---|---|---|
| Beam Type = | Tx54 | |
| No. Beams, $N_b$ = | 6 | |
| $CL_{brg}$ to $CL_{brg}$, L = | 50.38 | ft |
| Beam Spacing, S = | 8.00 | ft |
| Avg. Skew Angle, $\theta$ = | 0.00 | deg |
| Slab Thickness, $t_s$ = | 8 | in |
| Slab Overhang, OH = | 3 | ft |
| Rail Width, RW = | 1 | ft |
| Roadway Width, W = | 44 | ft |
| Number of Lanes, $N_L$ = | 3 | |

| Deck Slab | | |
|---|---|---|
| Conc wt = | 0.145 | $k/ft^3$ |
| $f'_c$ = | 4.0 | ksi |
| $E_{slab}$ = | 3644 | ksi |

| Beam | | |
|---|---|---|
| weight = | 0.145 | $k/ft^3$ |
| $f'_c$ = | 8.5 | ksi |
| $E_{beam}$ = | 5312 | ksi |
| $y_t$ = | 30.49 | in |
| A = | 817.0 | $in^2$ |
| I = | 299740 | $in^4$ |

Longitudinal Stiffness Parameter: (4.6.2.2.1-1)

$e_g$ (in) = 34.49 (dist. b/w cog of bm & deck)

n = 1.000

$K_g = n(I+Ae_g^2)$ = 1271611 $in^4$

**For typical cross sections (a,e,i,j & k). Table 4.6.2.2.1-1*

**RESULTS:**

| | Final LLDF |
|---|---|
| **Interior Shear LLDF, $gV_{interior}$** | **0.814** |
| **Interior Moment LLDF, $gM_{interior}$** | **0.794** |
| **Exterior Shear LLDF, $gV_{exterior}$** | **0.814** |
| **Exterior Moment LLDF, $gM_{exterior}$** | **0.794** |

The Final LLDF may be modified according to the following TxDOT policies:

- ♦ Exterior beams use the interior LLDF when OH ≤ S/2.
- ♦ When OH > S/2 the exterior beam LLDF is determined by the lever rule for a single lane with a multiple presence factor of 1.0.
- ♦ In no case shall the LLDF for the exterior beams be less than the LLDFs for the interior beams.
- ♦ When the Roadway width is less than 20ft, all beams are designed for one lane loaded only.
- ♦ In no case shall the LLDF be less than $m \cdot N_L \div N_b$.

**CALCULATIONS:**

**Shear LLDF Correction for Skew** (Table 4.6.2.2.3c-1)

$$\text{Corr.} = 1.0 + 0.20\left(\frac{12.0Lt_s^{\,3}}{K_g}\right)^{0.3}\tan\theta$$

= 1.0 + 0.20 * [(12.0*50.4*8^3)/(1,271,611)]^0.3 * tan(0)

Corr. = 1.000

| | | |
|---|---|---|
| Check $\theta$: | 0° ≤ 0° ≤ 60° | OK |
| Check S: | 3.5' ≤ 8.0' ≤ 16.0' | OK |
| Check L: | 20' ≤ 50.4' ≤ 240' | OK |
| Check $N_b$: | 6 ≥ 4 | OK |

**Moment LLDF Correction for Skew** (Table 4.6.2.2.2e-1)

Check $\theta$: 0° < 30° Set $\theta$ = 0°

Corr. = 1 - $c_1$(tan θ)^1.5

= 1 - 0(tan 0)^1.5

where: $$c_1 = 0.25\left(\frac{K_g}{12.0Lt_s^{\,3}}\right)^{0.25}\left(\frac{S}{L}\right)^{0.5}$$

Corr. = 1.000

$c_1$ = 0.000 because Θ < 30°

## INTERIOR BEAM:

Shear LL Distribution Per Lane (Table 4.6.2.2.3a-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.2 = 0.750

Modify for Skew:

skew correction = 1.000

mg = 0.750 * 1.000 = 0.750

Equation

$$g = 0.36 + \left(\frac{S}{25}\right)$$

g = 0.36 + (8 / 25) = 0.680

Modify for Skew:

skew correction = 1.000

g = 0.680 * 1.000 = 0.680

Range of Applicability (ROA) Checks

Check S: 3.5' ≤ 8.0' ≤ 16.0' OK

Check $t_s$: 4.5" ≤ 8.0" ≤ 12.0" OK

Check L: 20' ≤ 50.4' ≤ 240' OK

Check $N_b$: 6 ≥ 4 OK

Use Equation from Table 4.6.2.2.3a-1 because all criteria is OK.

$gV_{int1}$ = 0.680

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875

Modify for Skew:

skew correction = 1.000

mg = 0.875 * 1.000 = 0.875

Equation

$$g = 0.2 + \left(\frac{S}{12}\right) - \left(\frac{S}{35}\right)^{2.0}$$

g = 0.2 + (8 / 12) - (8 / 35)^2.0 = 0.814

Modify for Skew:

skew correction = 1.000

g = 0.814 * 1.000 = 0.814

Range of Applicability (ROA) Checks (same as for one lane loaded)

Use Equation from Table 4.6.2.2.3a-1 because all criteria is OK.

$gV_{int2+}$ = 0.814

TxDOT Policy states $gV_{Interior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is W ≥ 20ft ? Yes

TxDOT Policy states that if W < 20ft, $gV_{Interior}$ is the Maximum of: $gV_{int1}$ and $m \cdot N_L \div N_b$.

>> TxDOT Policy states that if W ≥ 20ft, $gV_{Interior}$ is the Maximum of: $gV_{int1}$, $gV_{int2+}$, $m \cdot N_L \div N_b$.

| $gV_{interior}$ = | **0.814** |
|---|---|

## INTERIOR BEAM:

Moment LL Distribution Per Lane (Table 4.6.2.2.2b-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.2 = 0.750

Modify for Skew:

skew correction = 1.000

mg = 0.750 * 1.000 = 0.750

Equation

$$g = 0.06 + \left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12Lt_s^{\,3}}\right)^{0.1}$$

g = 0.06 + (8/14)^0.4 * (8/50.4)^0.3 * (1,271,611/(12*50.4*8^3))^0.1 = 0.590

Modify for Skew:

skew correction = 1.000

g = 0.590 * 1.000 = 0.590

Range of Applicability (ROA) Checks

Check S: 3.5' ≤ 8.0' ≤ 16.0' OK

Check $t_s$: 4.5" ≤ 8.0" ≤ 12.0" OK

Check L: 20' ≤ 50.4' ≤ 240' OK

Check $N_b$: 6 ≥ 4 OK

Check $K_g$: 10,000 ≤ 1,271,611 ≤ 7,000,000 OK

Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.

$gM_{int1}$ = 0.590

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875

Modify for Skew:

skew correction = 1.000

mg = 0.875 * 1.000 = 0.875

Equation

$$g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^{\,3}}\right)^{0.1}$$

g = 0.075 + (8/9.5)^0.6 * (8/50.4)^0.2 * (1,271,611/(12*50.4*8^3))^0.1 = 0.794

Modify for Skew:

skew correction = 1.000

g = 0.794 * 1.000 = 0.794

Range of Applicability (ROA) Checks (same as for one lane loaded)

Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.

$gM_{int2+}$ = 0.794

TxDOT Policy states $gM_{Interior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is W ≥ 20ft ? Yes

TxDOT Policy states that if W < 20ft, $gM_{Interior}$ is the Maximum of: $gM_{int1}$ and $m \cdot N_L \div N_b$.

>> TxDOT Policy states that if W ≥ 20ft, $gM_{Interior}$ is the Maximum of: $gM_{int1}$, $gM_{int2+}$, $m \cdot N_L \div N_b$.

$gM_{interior}$ = **0.794**

**EXTERIOR BEAM:**

Shear LL Distribution Per Lane (Table 4.6.2.2.3b-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.0 = 0.625

TxDOT uses a multiple presence factor of 1.0 for one lane loaded on the exterior beam.

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1.

$gV_{ext1}$ = 0.625

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Equation

$d_e$ = dist. b/w CL web to curb

$d_e$ = OH - Rail Width

$d_e$ = 3ft - 1ft = 2.0 ft

$$e = 0.6 + \left(\frac{d_e}{10}\right)$$

e = 0.6 + (2.0/10) = 0.800

$g = e^*gV_{int2+Eq}$

g = 0.800 * 0.814 = 0.651

Skew Correction is included in gV(interior).

Range of Applicability (ROA) Checks

Interior ROA is implicitly applied to the exterior beam.

Check Interior Beam ROA: OK

Check $d_e$: -1.0' ≤ 2.0' ≤ 5.5' OK

Check $N_b$: 6 ≠ 3 OK

Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK.

$gV_{ext2+}$ = 0.651

TxDOT Policy states $gV_{Exterior}$ must be ≥ $gV_{interior}$

$gV_{interior}$ = 0.814

TxDOT Policy states $gV_{Exterior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is OH ≤ S/2 ? Yes

Is W ≥ 20ft ? Yes

>> TxDOT Policy states that if OH ≤ S/2, $gV_{Exterior}$ is $gV_{interior}$.

TxDOT Policy states that if OH > S/2 and W < 20ft, $gV_{Exterior}$ is the Maximum of: $gV_{ext1}$, $gV_{interior}$, and $m \cdot N_L \div N_b$.

TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, $gV_{Exterior}$ is the Maximum of: $gV_{ext1}$, $gV_{ext2+}$, $gV_{interior}$, and $m \cdot N_L \div N_b$.

$gV_{exterior}$ = **0.814**

## EXTERIOR BEAM:

Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):

**One Lane Loaded**

Lever Rule

mg = 0.625 * 1.0 = 0.625

TxDOT uses a multiple presence factor of 1.0 for one lane loaded on the exterior beam.

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.

$gM_{ext1}$ = 0.625

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Equation

$$e = 0.77 + \left(\frac{d_e}{9.1}\right)$$

e = 0.77 + (2.0/9.1) = 0.990

$g = e{*}gM_{int2+Eq}$

g = 0.99 * 0.794 = 0.786

Skew Correction included in gM(interior).

Range of Applicability (ROA) Checks

Interior ROA is implicitly applied to the exterior beam.

Check Interior Beam ROA: OK

Check $d_e$: -1.0' ≤ 2.0' ≤ 5.5' OK

Check $N_b$: 6 ≠ 3 OK

Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.

$gM_{ext2+}$ = 0.786

TxDOT Policy states $gM_{Exterior}$ must be ≥ $gM_{interior}$

$gM_{interior}$ = 0.794

TxDOT Policy states $gM_{Exterior}$ must be ≥ $m{\cdot}N_L{\div}N_b$

$m{\cdot}N_L{\div}N_b$ = 0.85 * 3 / 6 = 0.425

Is OH ≤ S/2 ? Yes

Is W ≥ 20ft ? Yes

\>> TxDOT Policy states that if OH ≤ S/2, $gM_{Exterior}$ is $gM_{interior}$.

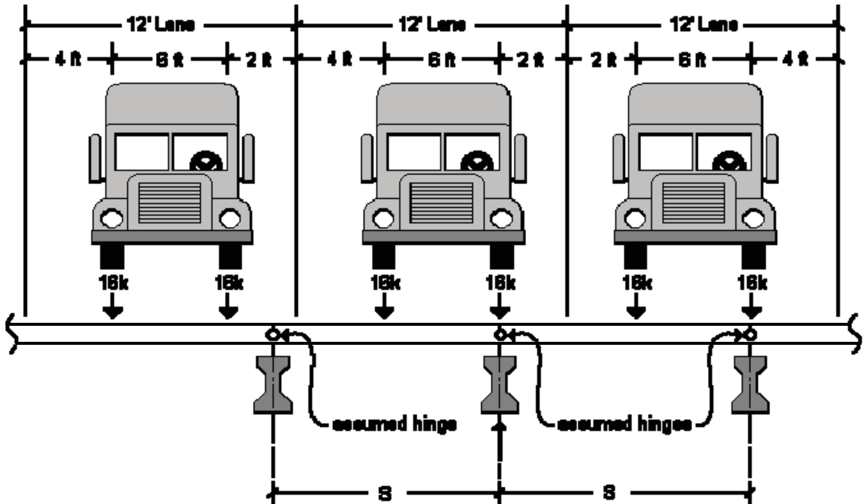
TxDOT Policy states that if OH > S/2 and W < 20ft, $gM_{Exterior}$ is the Maximum of: $gM_{ext1}$, $gM_{interior}$, and $m{\cdot}N_L{\div}N_b$.

TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, $gM_{Exterior}$ is the Maximum of: $gM_{ext1}$, $gM_{ext2+}$, $gM_{interior}$, and $m{\cdot}N_L{\div}N_b$.

**$gM_{exterior}$ = 0.794**

**LEVER RULE** S = 8.0 ft

INTERIOR




For S < 4:

One Lane = $\frac{16}{32}$ = 0.500

For 4 ≤ S < 6:

One Lane = $\frac{16}{32}$ = 0.500

Two Lanes = $\frac{16}{32}\left(1+\frac{S-4}{S}\right)$ = 0.750

>: **For 6 ≤ S < 10:**

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}\right)$ = 0.875

For 10 ≤ S < 12:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

For 12 ≤ S < 16:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}\right)$ = 0.500

For 16 ≤ S < 18:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}\right)$ = 0.500

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-16}{S}\right)$ = 0.000

**LEVER RULE** S = 8.0 ft

INTERIOR (con't)

For 18 ≤ S < 22:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}\right)$ = -0.125

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}+\frac{S-16}{S}\right)$ = -0.625

For 22 ≤ S ≤ 24:

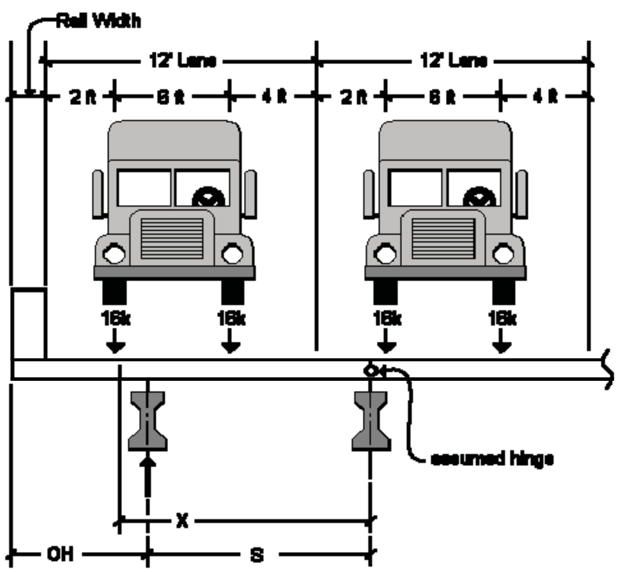
One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}\right)$ = -0.125

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}+\frac{S-16}{S}+\frac{S-22}{S}\right)$ = -1.500

EXTERIOR




S = 8.0 ft
OH = 3.0 ft
Rail Width = RW = 1.0 ft
X = S+OH-RW-2ft = 8.0 ft

For X < 6:

One Lane = $\frac{16}{32}\left(\frac{X}{S}\right)$ = 0.500

>: **For 6 ≤ X < 12:**

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

For 12 ≤ X < 18:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}\right)$ = 0.375

## LEVER RULE

EXTERIOR (con't) S = 8.0 ft OH = 3.0 ft

RW = 1.0 ft X = S+OH-RW-2ft = 8.0 ft

For 18 ≤ X < 24:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

For 24 ≤ X < 30:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}\right)$ = -1.250

For 30 ≤ X < 36:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

For 36 ≤ X < 42:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

Four Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}+\frac{X-36}{S}\right)$ = -4.375

For 42 ≤ X ≤ 48:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

Four Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}+\frac{X-36}{S}+\frac{X-42}{S}\right)$ = -6.500

| INTERIOR | | | EXTERIOR | | |
|---|---|---|---|---|---|
| One Lane Loaded | = | 0.625 | One Lane Loaded | = | 0.625 |
| Two Lanes Loaded | = | 0.875 | Two Lanes Loaded | = | 0.625 |
| Three Lanes Loaded | = | 0.875 | Three Lanes Loaded | = | 0.625 |
| Four Lanes Loaded | = | 0.875 | Four Lanes Loaded | = | 0.625 |

## LRFD Live Load Distribution Factors*

Live Load Distribution Factors are calculated according to AASHTO LRFD Bridge Design Specifications, 4th Edition (2007 with no interim revisions) as prescribed by TxDOT policies (LRFD Design Manual July 2008) and practices. The Lever Rule is used when outside the Range of Applicability. The Range of Applicability for the Skew Correction Factors is ignored.

**INPUT:**

| | | |
|---|---|---|
| Beam Type = | Tx54 | |
| No. Beams, $N_b$ = | 6 | |
| $CL_{brg}$ to $CL_{brg}$, L = | 106.75 | ft |
| Beam Spacing, S = | 8.00 | ft |
| Avg. Skew Angle, θ = | 0.00 | deg |
| Slab Thickness, $t_s$ = | 8 | in |
| Slab Overhang, OH = | 3 | ft |
| Rail Width, RW = | 1 | ft |
| Roadway Width, W = | 44 | ft |
| Number of Lanes, $N_L$ = | 3 | |

| Deck Slab | | |
|---|---|---|
| Conc wt = | 0.145 | k/ft$^3$ |
| f'$_c$ = | 4.0 | ksi |
| $E_{slab}$ = | 3644 | ksi |

| Beam | | |
|---|---|---|
| weight = | 0.145 | k/ft$^3$ |
| f'$_c$ = | 8.5 | ksi |
| $E_{beam}$ = | 5312 | ksi |
| $y_t$ = | 30.49 | in |
| A = | 817.0 | in$^2$ |
| I = | 299740 | in$^4$ |

Longitudinal Stiffness Parameter: (4.6.2.2.1-1)

$e_g$ (in) = 34.49 (dist. b/w cog of bm & deck)

n = 1.000

$K_g = n(I+Ae_g^2)$ = 1271611 in$^4$

*For typical cross sections (a,e,i,j & k). Table 4.6.2.2.1-1*

**RESULTS:**

| | Final LLDF |
|---|---|
| **Interior Shear LLDF, $gV_{interior}$** | **0.814** |
| **Interior Moment LLDF, $gM_{interior}$** | **0.649** |
| **Exterior Shear LLDF, $gV_{exterior}$** | **0.814** |
| **Exterior Moment LLDF, $gM_{exterior}$** | **0.649** |

The Final LLDF may be modified according to the following TxDOT policies:
- ♦ Exterior beams use the interior LLDF when OH ≤ S/2.
- ♦ When OH > S/2 the exterior beam LLDF is determined by the lever rule for a single lane with a multiple presence factor of 1.0.
- ♦ In no case shall the LLDF for the exterior beams be less than the LLDFs for the interior beams.
- ♦ When the Roadway width is less than 20ft, all beams are designed for one lane loaded only.
- ♦ In no case shall the LLDF be less than $m \cdot N_L \div N_b$.

**CALCULATIONS:**

**Shear LLDF Correction for Skew** (Table 4.6.2.2.3c-1)

$$\text{Corr.} = 1.0 + 0.20\left(\frac{12.0Lt_s^3}{K_g}\right)^{0.3}\tan\theta$$

= 1.0 + 0.20 * [(12.0*106.8*8^3)/(1,271,611)]^0.3 * tan(0)

Corr. = 1.000

| | | |
|---|---|---|
| Check θ: | 0° ≤ 0° ≤ 60° | OK |
| Check S: | 3.5' ≤ 8.0' ≤ 16.0' | OK |
| Check L: | 20' ≤ 106.8' ≤ 240' | OK |
| Check $N_b$: | 6 ≥ 4 | OK |

**Moment LLDF Correction for Skew** (Table 4.6.2.2.2e-1)

Check θ: 0° < 30° Set θ = 0°

Corr. = 1 - $c_1$(tan θ)^1.5

= 1 - 0(tan 0)^1.5

where: $$c_1 = 0.25\left(\frac{K_g}{12.0Lt_s^3}\right)^{0.25}\left(\frac{S}{L}\right)^{0.5}$$

Corr. = 1.000

$c_1$ = 0.000 because Θ < 30°

## INTERIOR BEAM:

Shear LL Distribution Per Lane (Table 4.6.2.2.3a-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.2 = 0.750

Modify for Skew:

skew correction = 1.000

mg = 0.750 * 1.000 = 0.750

Equation

$$g = 0.36 + \left(\frac{S}{25}\right)$$

g = 0.36 + (8 / 25) = 0.680

Modify for Skew:

skew correction = 1.000

g = 0.680 * 1.000 = 0.680

Range of Applicability (ROA) Checks

Check S: 3.5' ≤ 8.0' ≤ 16.0' OK

Check $t_s$: 4.5" ≤ 8.0" ≤ 12.0" OK

Check L: 20' ≤ 106.8' ≤ 240' OK

Check $N_b$: 6 ≥ 4 OK

Use Equation from Table 4.6.2.2.3a-1 because all criteria is OK.

$gV_{int1}$ = 0.680

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875

Modify for Skew:

skew correction = 1.000

mg = 0.875 * 1.000 = 0.875

Equation

$$g = 0.2 + \left(\frac{S}{12}\right) - \left(\frac{S}{35}\right)^{2.0}$$

g = 0.2 + (8 / 12) - (8 / 35)^2.0 = 0.814

Modify for Skew:

skew correction = 1.000

g = 0.814 * 1.000 = 0.814

Range of Applicability (ROA) Checks (same as for one lane loaded)

Use Equation from Table 4.6.2.2.3a-1 because all criteria is OK.

$gV_{int2+}$ = 0.814

TxDOT Policy states $gV_{Interior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is W ≥ 20ft ? Yes

TxDOT Policy states that if W < 20ft, $gV_{Interior}$ is the Maximum of: $gV_{int1}$ and $m \cdot N_L \div N_b$.

>> TxDOT Policy states that if W ≥ 20ft, $gV_{Interior}$ is the Maximum of: $gV_{int1}$, $gV_{int2+}$, $m \cdot N_L \div N_b$.

$gV_{interior}$ = **0.814**

## INTERIOR BEAM:

Moment LL Distribution Per Lane (Table 4.6.2.2.2b-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.2 = 0.750

Modify for Skew:

skew correction = 1.000

mg = 0.750 * 1.000 = 0.750

Equation

$$g = 0.06 + \left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12Lt_s^{\,3}}\right)^{0.1}$$

g = 0.06 + (8/14)^0.4 * (8/106.8)^0.3 * (1,271,611/(12*106.8*8^3))^0.1 = 0.453

Modify for Skew:

skew correction = 1.000

g = 0.453 * 1.000 = 0.453

Range of Applicability (ROA) Checks

Check S: 3.5' ≤ 8.0' ≤ 16.0' OK

Check $t_s$: 4.5" ≤ 8.0" ≤ 12.0" OK

Check L: 20' ≤ 106.8' ≤ 240' OK

Check $N_b$: 6 ≥ 4 OK

Check $K_g$: 10,000 ≤ 1,271,611 ≤ 7,000,000 OK

Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.

$gM_{int1}$ = 0.453

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875

Modify for Skew:

skew correction = 1.000

mg = 0.875 * 1.000 = 0.875

Equation

$$g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^{\,3}}\right)^{0.1}$$

g = 0.075 + (8/9.5)^0.6 * (8/106.8)^0.2 * (1,271,611/(12*106.8*8^3))^0.1 = 0.649

Modify for Skew:

skew correction = 1.000

g = 0.649 * 1.000 = 0.649

Range of Applicability (ROA) Checks (same as for one lane loaded)

Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.

$gM_{int2+}$ = 0.649

TxDOT Policy states $gM_{Interior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is W ≥ 20ft ? Yes

TxDOT Policy states that if W < 20ft, $gM_{Interior}$ is the Maximum of: $gM_{int1}$ and $m \cdot N_L \div N_b$.

>> TxDOT Policy states that if W ≥ 20ft, $gM_{Interior}$ is the Maximum of: $gM_{int1}$, $gM_{int2+}$, $m \cdot N_L \div N_b$.

$gM_{interior}$ = **0.649**

## EXTERIOR BEAM:

Shear LL Distribution Per Lane (Table 4.6.2.2.3b-1):

**One Lane Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = 0.625 * 1.0 = 0.625

TxDOT uses a multiple presence factor of 1.0 for one lane loaded on the exterior beam.

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1.

$gV_{ext1}$ = 0.625

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Equation

$d_e$ = dist. b/w CL web to curb

$d_e$ = OH - Rail Width

$d_e$ = 3ft - 1ft = 2.0 ft

$$e = 0.6 + \left(\frac{d_e}{10}\right)$$

e = 0.6 + (2.0/10) = 0.800

$g = e^*gV_{int2+Eq}$

g = 0.800 * 0.814 = 0.651

Skew Correction is included in gV(interior).

Range of Applicability (ROA) Checks

Interior ROA is implicitly applied to the exterior beam.

Check Interior Beam ROA: OK

Check $d_e$: -1.0' ≤ 2.0' ≤ 5.5' OK

Check $N_b$: 6 ≠ 3 OK

Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK.

$gV_{ext2+}$ = 0.651

TxDOT Policy states $gV_{Exterior}$ must be ≥ $gV_{interior}$

$gV_{interior}$ = 0.814

TxDOT Policy states $gV_{Exterior}$ must be ≥ $m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is OH ≤ S/2 ? Yes

Is W ≥ 20ft ? Yes

>> TxDOT Policy states that if OH ≤ S/2, $gV_{Exterior}$ is $gV_{interior}$.

TxDOT Policy states that if OH > S/2 and W < 20ft, $gV_{Exterior}$ is the Maximum of: $gV_{ext1}$, $gV_{interior}$, and $m \cdot N_L \div N_b$.

TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, $gV_{Exterior}$ is the Maximum of: $gV_{ext1}$, $gV_{ext2+}$, $gV_{interior}$, and $m \cdot N_L \div N_b$.

$gV_{exterior}$ = **0.814**

**EXTERIOR BEAM:**

Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):

**One Lane Loaded**

Lever Rule

mg = 0.625 * 1.0 = 0.625

TxDOT uses a multiple presence factor of 1.0 for one lane loaded on the exterior beam.

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.

$gM_{ext1}$ = 0.625

**Two or More Lanes Loaded**

Lever Rule (Table 3.6.1.1.2)

mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625

Modify for Skew:

skew correction = 1.000

mg = 0.625 * 1.000 = 0.625

Equation

$$e = 0.77 + \left(\frac{d_e}{9.1}\right)$$

e = 0.77 + (2.0/9.1) = 0.990

$g = e * gM_{int2+Eq}$

g = 0.99 * 0.649 = 0.643

Skew Correction included in gM(interior).

Range of Applicability (ROA) Checks

Interior ROA is implicitly applied to the exterior beam.

Check Interior Beam ROA: OK

Check $d_e$: $-1.0' \le 2.0' \le 5.5'$ OK

Check $N_b$: $6 \neq 3$ OK

Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.

$gM_{ext2+}$ = 0.643

TxDOT Policy states $gM_{Exterior}$ must be $\ge gM_{interior}$

$gM_{interior}$ = 0.649

TxDOT Policy states $gM_{Exterior}$ must be $\ge m \cdot N_L \div N_b$

$m \cdot N_L \div N_b$ = 0.85 * 3 / 6 = 0.425

Is OH ≤ S/2 ? Yes

Is W ≥ 20ft ? Yes

>> TxDOT Policy states that if OH ≤ S/2, $gM_{Exterior}$ is $gM_{interior}$.

TxDOT Policy states that if OH > S/2 and W < 20ft, $gM_{Exterior}$ is the Maximum of: $gM_{ext1}$, $gM_{interior}$, and $m \cdot N_L \div N_b$.

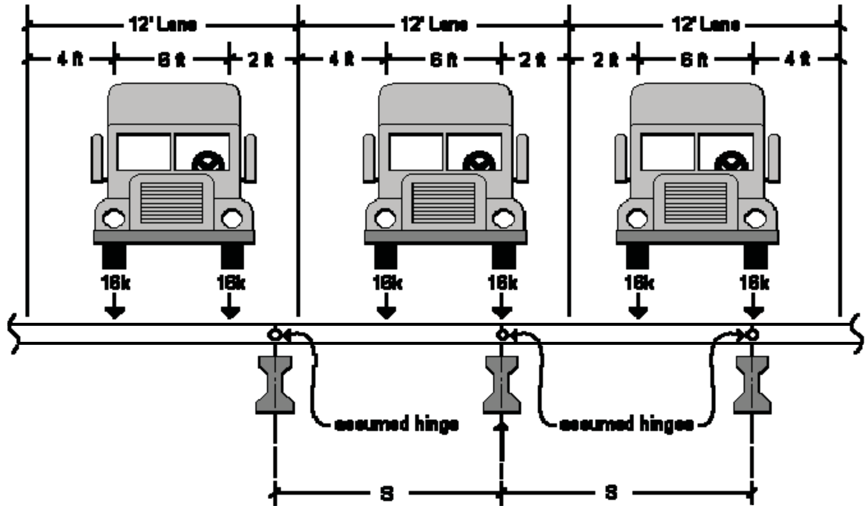
TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, $gM_{Exterior}$ is the Maximum of: $gM_{ext1}$, $gM_{ext2+}$, $gM_{interior}$, and $m \cdot N_L \div N_b$.

**$gM_{exterior}$ = 0.649**

| TXDOT BRIDGE DIVISION | County: | ANY | Highway: | Any | Design: | BRG | Date: | 2/2/10 | 2007 LRFD Specs |
|---|---|---|---|---|---|---|---|---|---|
| | C-S-J: | XXX-XX-XXXX | ID #: | XXXX | Ck Dsn: | BRG | Date: | | Rev. 8/08 - (No Interim) |
| | Descrip: | Inverted Tee Design Example, Span 2 | | | File: | distribution_factors_i.xls | | | Sheet: 6 of 8 |

**LEVER RULE** S = 8.0 ft

INTERIOR




For S < 4:

One Lane = $\frac{16}{32}$ = 0.500

For 4 ≤ S < 6:

One Lane = $\frac{16}{32}$ = 0.500

Two Lanes = $\frac{16}{32}\left(1+\frac{S-4}{S}\right)$ = 0.750

>: **For 6 ≤ S < 10:**

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}\right)$ = 0.875

For 10 ≤ S < 12:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

For 12 ≤ S < 16:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}\right)$ = 0.500

For 16 ≤ S < 18:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}\right)$ = 0.500

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-16}{S}\right)$ = 0.000

## LEVER RULE

S = 8.0 ft

INTERIOR (con't)

For 18 ≤ S < 22:

One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}\right)$ = -0.125

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}+\frac{S-16}{S}\right)$ = -0.625

For 22 ≤ S ≤ 24:

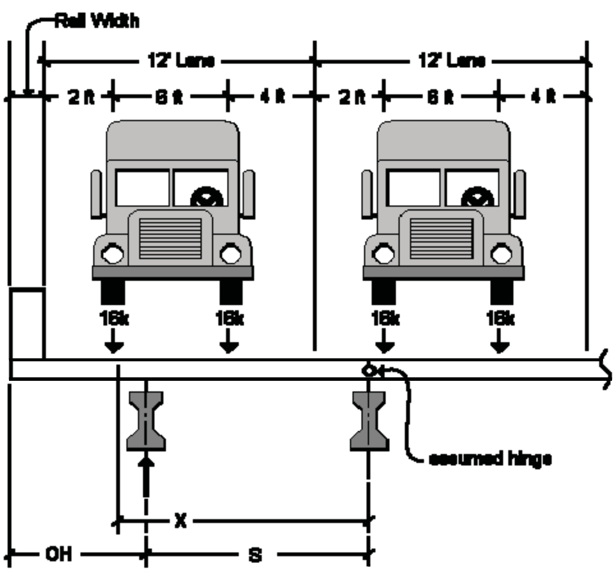
One Lane = $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}\right)$ = 0.750

Three Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}\right)$ = -0.125

Four Lanes = $\frac{16}{32}\left(1+\frac{S-6}{S}+\frac{S-4}{S}+\frac{S-10}{S}+\frac{S-12}{S}+\frac{S-18}{S}+\frac{S-16}{S}+\frac{S-22}{S}\right)$ = -1.500

EXTERIOR




S = 8.0 ft
OH = 3.0 ft
Rail Width = RW = 1.0 ft
X = S+OH-RW-2ft = 8.0 ft

For X < 6:

One Lane = $\frac{16}{32}\left(\frac{X}{S}\right)$ = 0.500

>: **For 6 ≤ X < 12:**

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

For 12 ≤ X < 18:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}\right)$ = 0.375

## LEVER RULE

EXTERIOR (con't) S = 8.0 ft OH = 3.0 ft
RW = 1.0 ft X = S+OH-RW-2ft = 8.0 ft

For 18 ≤ X < 24:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

For 24 ≤ X < 30:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}\right)$ = -1.250

For 30 ≤ X < 36:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

For 36 ≤ X < 42:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

Four Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}+\frac{X-36}{S}\right)$ = -4.375

For 42 ≤ X ≤ 48:

One Lane = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ = 0.625

Two Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}\right)$ = -0.250

Three Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}\right)$ = -2.625

Four Lanes = $\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}+\frac{X-12}{S}+\frac{X-18}{S}+\frac{X-24}{S}+\frac{X-30}{S}+\frac{X-36}{S}+\frac{X-42}{S}\right)$ = -6.500

| INTERIOR | | | EXTERIOR | | |
|---|---|---|---|---|---|
| One Lane Loaded | = | 0.625 | One Lane Loaded | = | 0.625 |
| Two Lanes Loaded | = | 0.875 | Two Lanes Loaded | = | 0.625 |
| Three Lanes Loaded | = | 0.875 | Three Lanes Loaded | = | 0.625 |
| Four Lanes Loaded | = | 0.875 | Four Lanes Loaded | = | 0.625 |

Texas Department of Transportation

| | | | | | |
|---|---|---|---|---|---|
| County: | Any | Descrip: | LRFD Inverted Tee Cap Design Example - Bent 2 | | |
| Highway: | Any | | | | |
| C-S-J: | XXXX-XX-XXX | Design: | BRG | Ck Dsn: | BRG |
| **Bridge Division** | Rev: 09/26/08 | | | Date: | Apr-10 |

## CONCRETE SECTION SHEAR CAPACITY BY AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, FOURTH EDITION, 2007

Units: **US**

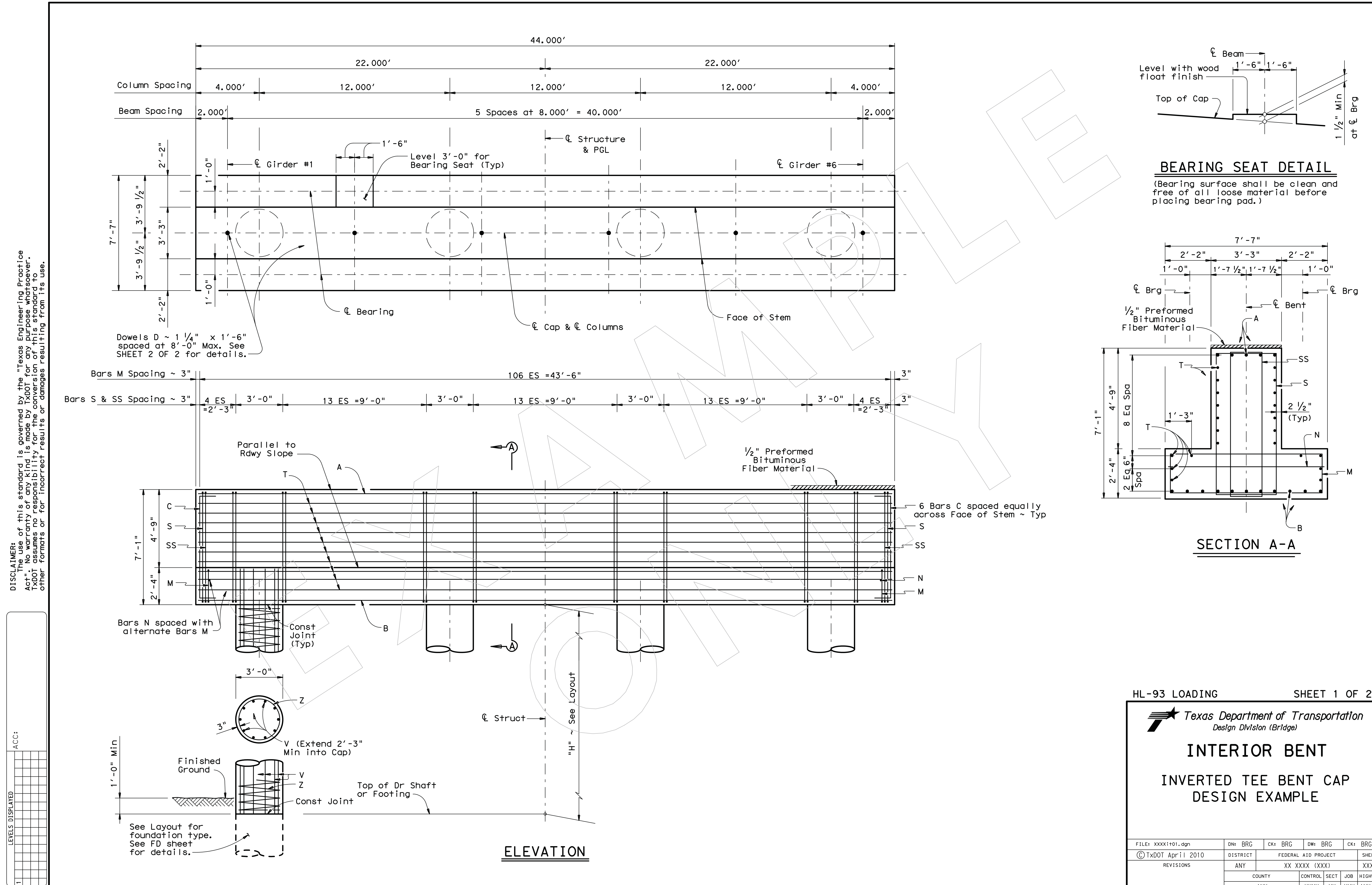
**Resistance Factors:**

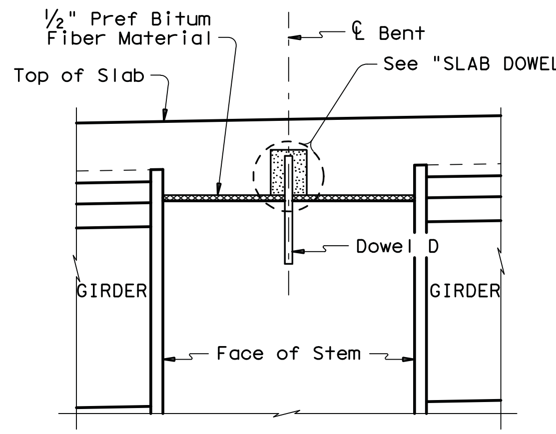
| | |
|---|---|
| $\phi_V$ = | 0.9 |
| $\phi_M$ = | 0.9 |
| $\phi_N$ = | 0.75 |

| **Concrete:** | | | **Mild Steel:** | | | **Prestressed Steel:** | | |
|---|---|---|---|---|---|---|---|---|
| f'c = | 3.6 | ksi | fy = | 60 | ksi | fpu = | 270 | ksi |
| Ec = | 3453 | ksi | Es = | 29000 | ksi | Ep = | 28500 | ksi |

| | | SECTIONS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Units | **8** | **12** | **32** | **36** | **56** | **60** | **80** | **84** |
| **Input Data** | | | | | | | | | |
| Bending moment, **Mu** | kip-ft | 429.2 | 619.9 | 507.9 | 335.6 | 335.6 | 507.9 | 619.9 | 429 |
| Shear force, **Vu** | kip | 419.8 | 239.8 | 247.3 | 448.1 | 448.1 | 247.3 | 239.8 | 419.8 |
| Axial force, **Nu (+ if tensile)** | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Web width, **bv** | in | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 |
| Shear depth, **dv** | in | 80.58 | 80.58 | 80.58 | 80.58 | 80.58 | 80.58 | 80.58 | 80.58 |
| Mild steel reinf. area, **As** | in^2 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 |
| Conc area on tension side, **Ac** | in^2 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 |
| Area of stirrups, **Av** | in^2 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 |
| Stirrup spacing, **s** | in | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Prestressed steel area, **Aps** | in^2 | | | | | | | | |
| Prestress shear, **Vp** | kip | | | | | | | | |
| Average prestress, **fps** | ksi | | | | | | | | |
| Torsional moment, **Tu** | kip-ft | 660 | 330 | 330 | 660 | 660 | 330 | 330 | 660 |
| Shear flow area, **Ao** | in^2 | 3329 | 3329 | 3329 | 3329 | 3329 | 3329 | 3329 | 3329 |
| Area of one leg of stirrup, **At** | in^2 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 |
| Perimeter of stirrup, **Ph** | in | 332 | 332 | 332 | 332 | 332 | 332 | 332 | 332 |
| **Calculated Values** | | | | | | | | | |
| **Vc** | kip | 420.2 | 431.5 | 427.7 | 420.2 | 420.2 | 427.7 | 431.5 | 420.2 |
| **Vs** | kip | 1251.3 | 1355.4 | 1345.1 | 1251.3 | 1251.3 | 1345.1 | 1355.4 | 1251.3 |
| **$\phi$Vn** | kip | **1504** | **1608** | **1595** | **1504** | **1504** | **1595** | **1608** | **1504** |
| $\varepsilon_x$ | | 1.00E-03 | 9.03E-04 | 9.28E-04 | 1.00E-03 | 1.00E-03 | 9.28E-04 | 9.03E-04 | 1.00E-03 |
| $\theta$ | deg | 36.40 | 35.40 | 35.60 | 36.40 | 36.40 | 35.60 | 35.40 | 36.40 |
| $\beta$ | | 2.230 | 2.290 | 2.270 | 2.230 | 2.230 | 2.270 | 2.290 | 2.230 |
| Req'd Shear reinf. **Av/S** | in^2/in | 0.007 | 0.000 | 0.000 | 0.012 | 0.012 | 0.000 | 0.000 | 0.007 |
| Req'd Torsion reinf. **At/S** | in^2/in | 0.016 | 0.008 | 0.008 | 0.016 | 0.016 | 0.008 | 0.008 | 0.016 |
| Maximum stirrup spacing, Smax | in | 24.0 | 24.0 | 24.0 | 22.9 | 22.9 | 24.0 | 24.0 | 24.0 |
| ***Conclusion*** | | | | | | | | | |
| Shear Reinforcing | | OK | OK | OK | OK | OK | OK | OK | OK |
| Longitudinal Reinforcing | | FAILED | OK | OK | FAILED | FAILED | OK | OK | FAILED |

Note: Longitudinal Reinforcing check can be ignored for typical multi-column bent caps. For straddle bents with no overhangs, this check must be considered. Refer to LRFD 5.8.3.5 for further information.
If torsion is not being considered, leave last five rows of input data blank.


DISCLAIMER: The use of this standard is governed by the "Texas Engineering Practice Act". No warranty of any kind is made by TxDOT for any purpose whatsoever. TxDOT assumes no responsibility for the conversion of this standard to other formats or for incorrect results or damages resulting from its use.
44.000'
22.000'
22.000'
Column Spacing
4.000'
12.000'
12.000'
12.000'
4.000'
Beam Spacing
2.000'
5 Spaces at 8.000' = 40.000'
2.000'
℄ Structure & PGL
1'-6"
Level 3'-0" for Bearing Seat (Typ)
℄ Girder #1
℄ Girder #6
7'-7"
2'-2"
3'-9 ½"
3'-3"
3'-9 ½"
2'-2"
1'-0"
1'-0"
℄ Bearing
℄ Cap & ℄ Columns
Face of Stem
Dowels D ~ 1 ¼" x 1'-6" spaced at 8'-0" Max. See SHEET 2 OF 2 for details.
Bars M Spacing ~ 3"
106 ES =43'-6"
3"
Bars S & SS Spacing ~ 3"
4 ES =2'-3"
3'-0"
13 ES =9'-0"
3'-0"
13 ES =9'-0"
3'-0"
13 ES =9'-0"
3'-0"
4 ES =2'-3"
3"
Parallel to Rdwy Slope
A
T
A
½" Preformed Bituminous Fiber Material
C
S
SS
M
7'-1"
4'-9"
2'-4"
6 Bars C spaced equally across Face of Stem ~ Typ
S
SS
N
M
Bars N spaced with alternate Bars M
Const Joint (Typ)
B
A
3'-0"
Z
3"
V (Extend 2'-3" Min into Cap)
℄ Struct
"H" ~ See Layout
1'-0" Min
Finished Ground
V
Z
Const Joint
Top of Dr Shaft or Footing
See Layout for foundation type. See FD sheet for details.
ELEVATION
℄ Beam
1'-6"
1'-6"
Level with wood float finish
Top of Cap
1 ½" Min at ℄ Brg
BEARING SEAT DETAIL
(Bearing surface shall be clean and free of all loose material before placing bearing pad.)
7'-7"
2'-2"
3'-3"
2'-2"
1'-0"
1'-7 ½"
1'-7 ½"
1'-0"
℄ Brg
℄ Bent
℄ Brg
½" Preformed Bituminous Fiber Material
A
SS
T
S
2 ½" (Typ)
7'-1"
4'-9"
8 Eq Spa
1'-3"
T
N
M
2'-4"
2 Eq 6" Spa
B
SECTION A-A
HL-93 LOADING
SHEET 1 OF 2
Texas Department of Transportation
Design Division (Bridge)
INTERIOR BENT
INVERTED TEE BENT CAP DESIGN EXAMPLE
FILE: XXXXit01.dgn
DN: BRG
CK: BRG
DW: BRG
CK: BRG
©TxDOT April 2010
DISTRICT
FEDERAL AID PROJECT
SHEET
REVISIONS
ANY
XX XXXX (XXX)
XXX
COUNTY
CONTROL
SECT
JOB
HIGHWAY
ANY
XXXX
XX
XXX
ANY
LEVELS DISPLAYED
ACC:
1



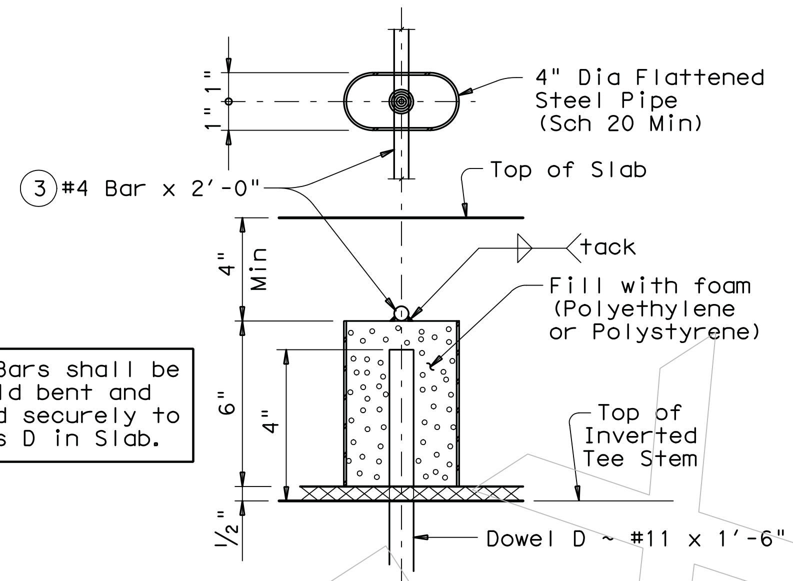

LONGITUDINAL SECT THRU SLAB AT INVERTED-TEE BENT

| TABLES OF CONSTANT QUANTITIES | | | | |
|---|---|---|---|---|
| Bar | No. | Size | Length | Weight |
| A | 5 | #11 | 43'-8" | 1160 |
| B | 11 | #11 | 43'-8" | 2552 |
| C | 12 | # 5 | 8'-7" | 107 |
| D | 6 | #11 | 1'-6" | 48 |
| M | 107 | #6 | 20'-2" | 3241 |
| N | 54 | #6 | 7'-3" | 588 |
| S | 52 | #6 | 21'-0" | 1640 |
| SS | 55 | #6 | 18'-10" | 1471 |
| T | 20 | #6 | 43'-8" | 1443 |
| Reinforcing Steel | | | Lb | 12,250 |
| Class "C" Concrete | | | CY | 54.4 |

| ① TABLE OF VARIABLE QUANTITIES FOR 4 COLUMNS | | | | | | ② TOTAL ESTIMATED QUANTITIES | |
|---|---|---|---|---|---|---|---|
| "H" | Class "C" Conc (Cols) | Bars V 40 ~ #9 | | Bars Z 4 ~ #3 Spiral | | Reinf Steel | Class "C" Conc |
| Ft | CY | Length | Weight | Length | Weight | Lb | CY |
| 22 | 23.0 | 24'-3" | 3,298 | 362' | 544 | 15,962 | 77.4 |
| 12 | 12.6 | 14'-3" | 1,938 | 205' | 308 | 14,366 | 67.0 |

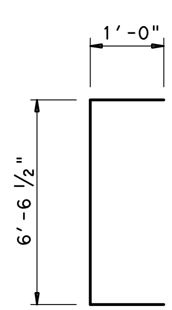
① Adjust Bars V length by 1 Ft and Bars Z length by 15.740 Ft for each linear foot of variation in "H" value.

② Adjust Reinforcing Steel Total by 160 Lbs and Class "C" Conc by 1.047 CY for each linear foot of variation in "H" value.

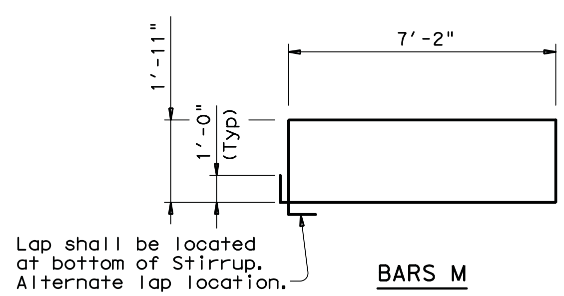



SLAB DOWEL D DETAIL

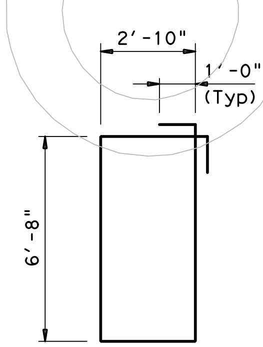
③ #4 Bars shall be field bent and tied securely to Bars D in Slab.



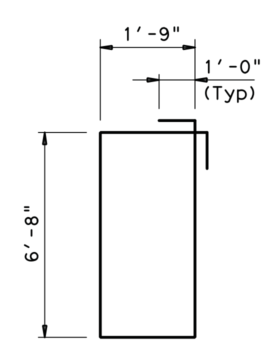

BARS C



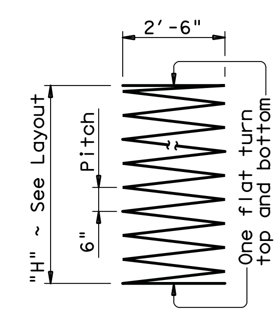

BARS M




BARS S




BARS SS




BARS Z

GENERAL NOTES:
Designed according to AASHTO LRFD Bridge Design Specifications, 5th Edition (2010).
Class "C" concrete strength f'c = 3,600 psi.
All Cap reinforcing shall be Grade 60.
Column and Drilled Shaft reinforcing may be Grade 40.
See Foundation Detail Standard Sheet, FD, for all foundation details and notes.
Calculated Foundation Load = 210 Tons/Dr Shaft

HL-93 LOADING SHEET 2 OF 2

Texas Department of Transportation
Design Division (Bridge)

INTERIOR BENT

INVERTED TEE BENT CAP DESIGN EXAMPLE

| FILE: xxxxit01.dgn | DN: BRG | CK: BRG | DW: BRG | CK: BRG |
|---|---|---|---|---|
| ©TxDOT June 2010 | DISTRICT | FEDERAL AID PROJECT | | SHEET |
| REVISIONS | ANY | XX XXXX (XXX) | | XXX |
| | COUNTY | CONTROL | SECT | JOB | HIGHWAY |
| | ANY | XXXX | XX | XXX | ANY |



LEVELS DISPLAYED
ACC:
1