Texas Department of Transportation

BRIDGE DIVISION

County: Any Hwy: Any Design: BRG Date: 05/2010

CSJ: Any Ck Dsn: BRG Date: 05/2010

Bearing Pad 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).

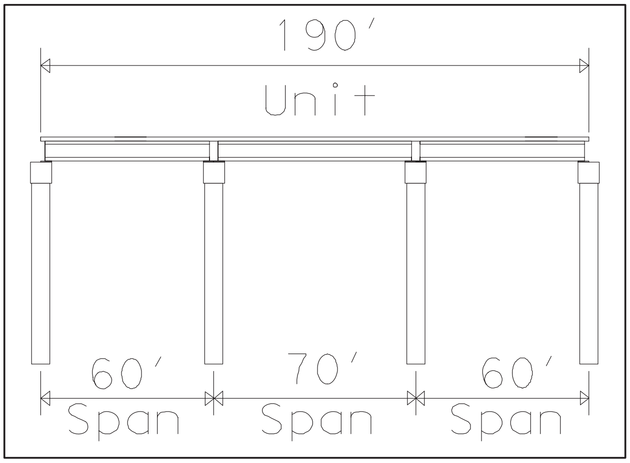
The usual starting place for "designing" elastomeric bearings is an analysis of the standard pad configurations for applicability to the superstructure geometry. In particular, the pads must satisfy slip and shear requirements for the designed unit length. Other factors such as compressive stress, deflection, stability, rotation, and bearing seat geometry are typically accounted for in the standard pad design. When using a standard bridge with standard bearing pads it is only necessary to perform the slip check and the shear check.

The intention of the original design for the bearing pads represented on the IBEB & IGEB Standard sheets was to make the pads usable for all simple spans, all two span units, and a large number of three span units. Due to all the conditions that can reduce the dead load on the end bearings (narrow beam spacing, short end span, severe beam slope) and thereby increase the chance for slip, good engineering judgment dictates checking the standard pad for suitability on any continuous unit with three or more spans.

For purposes of illustrating TxDOT's design method, the example below will examine all the requirements. A standard pad will typically pass the shear check if the unit is less than 400' in length, and it will typically pass the slip check if the unit is less than 3 times the length of the smallest span. In general, designers should be more conservative on stability (both construction and final) and slip, and liberal on compressive allowable stresses.

## Unit Information: (3-Span Prestressed Concrete I-Girder Unit)

This design example will check the standard bearing pad for the Tx40 Girder. The bridge has prestressed concrete girders (Tx40), T551 rails, and a 30 degree skew. Slip will be checked for the shortest span (60ft), and all other checks will be preformed for the longest span (70 ft).



*"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.*

$N_{span}$ = Number of Spans in the unit $N_{span} = 3$

$L_{unit}$ = Total Length of the Unit

$L_{unit} = 60\ ft + 70\ ft + 60\ ft$ $L_{unit} = 190\,ft$

$W_{bridge}$ = Width of the Bridge $W_{bridge} = 46\ ft$

## **Unit Information:** (Con't)

$t_s$ = Thickness of Bridge Slab — $t_s = 8\ \text{in}$

$w_c$ = Unit Weight of Concrete for Loads — $w_c = 0.150\ \text{kcf}$

$w_{Olay}$ = Unit Weight of Overlay — $w_{Olay} = 0.140\ \text{kcf}$

$Wt_{girder}$ = Weight of Girder — $Wt_{girder} = 0.697\ \dfrac{\text{klf}}{\text{beam}}$

$Wt_{rail}$ = Weight of Rail — $Wt_{rail} = 0.382\ \dfrac{\text{klf}}{\text{rail}}$

$N_{girder}$ = Number of Girders in Span — $N_{girder} = 6$

Gr = Max Beam Slope From RDS — $Gr = 0.0093\ \dfrac{\text{ft}}{\text{ft}}$

Skew = Bridge Skew — $Skew = 30\ \text{deg}$

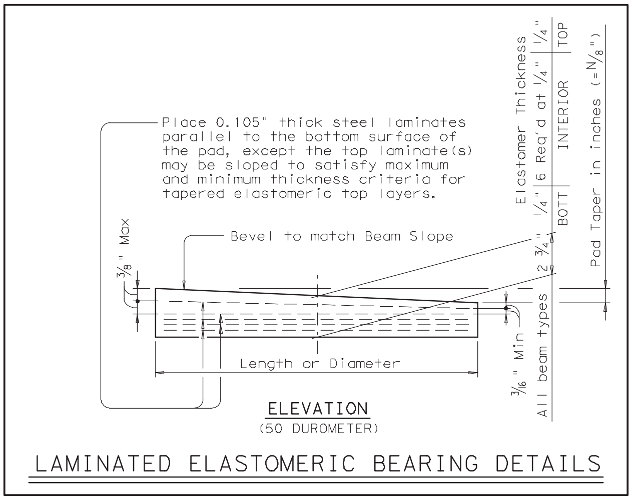
Although the skew is shown in this design example and would affect the pad area, it is not used in any of the below calculations since the area reduction of no more than 10%, due to clipped pads, is not a concern. For further explanation see Appendix A on pg. 11.

## Bearing Pad Information:

*(IGEB Standard)*

Check Standard Pad for Ty Tx40 Beam

The minimum overall thickness for a bearing pad should be at least 1 1/2" of elastomer (i.e., excluding plate thickness) to help the bearing compensate for beam and bearing seat build-up non parallelism, and/or surface irregularities. Certain cases where the designer needs to accommodate tight construction clearance limitations, match existing profile grades using existing caps, etc., may also be sufficient reason to violate this general rule of thumb for minimum elastomer thickness.



LAMINATED ELASTOMERIC BEARING DETAILS

Elastomer = 50 Durometer Neoprene

*50 Durometer Neoprene is standard, but for beams on a severe grade and horizontal displacement 60 or 70 Durometer Neoprene may be desired. For additional information see report 1304-3.*

$h_{ro}$ = Thickness of individual outer (top and bottom) layers of elastomer — $h_{ro} = 0.25\ \text{in}$

$n_{ro}$ = Number of the outer layers of elastomer — $n_{ro} = 2$

$h_{rto}$ = Total thickness of the outer layers of elastomer

$$h_{rto} = h_{ro} \cdot n_{ro} \qquad h_{rto} = 0.5 \cdot \text{in}$$

$h_{ri}$ = Thickness of individual interior layers of elastomer — $h_{ri} = 0.25\ \text{in}$

$n_{ri}$ = Number of the interior layers of elastomer — $n_{ri} = 6$

$h_{rti}$ = Total thickness of the interior layers of elastomer

$$h_{rti} = h_{ri} \cdot n_{ri} \qquad h_{rti} = 1.5 \cdot \text{in}$$

## Bearing Pad Information: (Con't)

$h_{rt}$ = Total thickness of the layers of elastomer

$h_{rt} = h_{rto} + h_{rti}$ $\qquad$ $h_{rt} = 2 \cdot in$

$h_s$ = Thickness of individual layers of reinforcement; 12 gauge steel plates; $\qquad$ $h_s = 0.105 \ in$

$n_s$ = Number of steel layers $\qquad$ $n_s = 7$

$F_y$ = Yield Strength of steel layers $\qquad$ $F_y = 36 \ ksi$

h = Total Bearing Pad Height

$h = h_{rt} + n_s \cdot h_s$ $\qquad$ $h = 2.735 \cdot in$

L = Length of the bearing pad, perpendicular to bridge long axis $\qquad$ $L = 8 \ in$

W = Width of the bearing pad, parallel to bridge long axis $\qquad$ $W = 21 \ in$

*Refer to Appendix B on pg. 15, Table B-2 or IGEB Standard for bearing pad size.*

For additional information on tapers, overall geometry and general information see Appendix A starting on pg. 11.

## Shape Factor: *(AASHTO LRFD 14.7.5.1)*

A = Plan Area of the Bearing Pad

$A = L \cdot W$ $\qquad$ $A = 168 \cdot in^2$

$A_{bi}$ = Area of perimeter free to bulge for an individual interior layer of elastomer

$A_{bi} = 2 \cdot (L + W) \cdot h_{ri}$ $\qquad$ $A_{bi} = 14.5 \cdot in^2$

$S_i$ = Shape factor for an individual interior layer of elastomer

$S_i = \frac{A}{A_{bi}}$ $\qquad$ $S_i = 11.586$

The target shape factor range is 10.0 to 12.0 (TxSP), to utilize the compressive capacity. If the shape factor is below 10.0 the capacity decreases, and if the shape factor is above 12.0 it does not supply any extra capacity due to the 1.2 ksi cap on the compressive capacity.

## Shear Modulus: *(BDM-LRFD Ch 5, Sect. 2, "Materials")*

$G_{73} = 95 \ psi$ at 73°F

$G_0 = 175 \ psi$ at 0°F

There is a range of values for the shear modulus (95-130 psi) that you may actually receive from the fabricator when you specify 50 Durometer. After the research for Report 1304-3, TxDOT decided to use Yura's suggested value of 95 psi since it is conservative.

## Stability Check:

*(AASHTO LRFD 14.7.6.3.6)*

$h_{rtMax}$ = Maximum Allowable Total Elastomer Height

$h_{rtMax}$ is the smaller of:

*Use $h_{rt}$ instead of the total pad height (BDS-LRFD, Ch. 5, Sect. 2, "Design Criteria").*

$$\frac{L}{3} = 2.667\cdot in \quad \& \quad \frac{W}{3} = 7\cdot in$$

$$h_{rtMax} = 2.667\cdot in$$

$$h_{rt} = 2\cdot in$$

*(calculated on pg. 3)*

$h_{rtMax}$ is greater than $h_{rt}$ therefore OK.

## Shear Check:

*(AASHTO LRFD 14.7.6.3.4)*

α = Coefficient of Thermal Expansion

$$\alpha = 6 \times 10^{-6} \frac{in}{in\cdot degF}$$

*(AASHTO LRFD 5.4.2.2)*

ΔT = Temerature range for design

$$\Delta T = 70\ degF$$

*Use 70 degrees as the Design Tempreture Range (BDM-LRFD, Ch. 5, Sect. 2, "Structural Analysis") For bridges in the panhandle region use 105 degrees.*

$\Delta_{sx}$ = max. total shear deformation of the elastomer at service limit state in the longitudinal direction of the bridge

$$\Delta_{sx} = \alpha\cdot\frac{L_{unit} + W_{bridge}\cdot\sin(Skew)}{2}\cdot\Delta T \qquad \Delta_{sx} = 0.537\cdot in$$

*Expanding length of prestressed concrete beam units can be taken as 1/2 total unit length. For highly skewed bridges and very wide bridges, take expanding length on a diagonal between slab corners to obtain the most unfavorable expansion length (TxSP).*

$\Delta_{sy}$ = max. total shear deformation of the elastomer at service limit state in the transverse direction of the bridge

$$\Delta_{sy} = \alpha\cdot\frac{W_{bridge}}{2}\cdot 70\ degF \qquad \Delta_{sy} = 0.116\cdot in$$

$\Delta_s$ = max. total shear deformation of the elastomer at service limit state

$$\Delta_s = \sqrt{\Delta_{sx}^{\ 2} + \Delta_{sy}^{\ 2}} \qquad \Delta_s = 0.549\cdot in$$

Current AASHTO specifications suggest a 50% maximum shear strain limit. Therefore, the pad elastomer material (steel plate thickness not included) total thickness must be twice the expected thermal movement at the bearing.

$h_{rtMin}$ = Minimum Allowable Total Elastomer Height

$$h_{rtMin} = 2\Delta_s \qquad h_{rtMin} = 1.098\cdot in$$

$$h_{rt} = 2\cdot in$$

*(calculated on pg. 3)*

$h_{rt}$ is greater than $h_{rtMin}$ therefore OK.

## Loads (Short Span):

$\text{Span} = 60\ \text{ft}$

$t_{Olay} = 0\ \text{in}$

*Thickness of Overlay*

*There is no overlay on the bridge. The 2" future overlay is not considered since the lightest dead load is conservative for the slip check.*

**Dead Load:**

$\text{Beam}_{DL} = \text{Wt}_{girder} \cdot \frac{\text{Span}}{2}$ $\text{Beam}_{DL} = 20.91 \cdot \text{kip}$

$\text{Slab}_{DL} = w_c \cdot t_s \cdot \frac{W_{bridge}}{N_{girder}} \cdot \frac{\text{Span}}{2}$ $\text{Slab}_{DL} = 23.00 \cdot \text{kip}$

$\text{Rail}_{DL} = \frac{2\ \text{rails} \cdot \text{Wt}_{rail}}{N_{girder}} \cdot \frac{\text{Span}}{2}$ $\text{Rail}_{DL} = 3.82 \cdot \text{kip}$

*Distribute rail load to all beams for the lightest load.*

$\text{DL} = \text{Beam}_{DL} + \text{Slab}_{DL} + \text{Rail}_{DL}$ $\text{DL} = 47.73 \cdot \text{kip}$

## Bearing Pad Slip Check: (Service Limit)

*(BDM-LRFD Ch. 5, Sect. 2, "Design Criteria")*

Use the shear modulus "$G_0$" (modulus at 0 deg F) for the slip check because the pad is stiffer at colder temperatures and therefore produces larger shear forces when the beam contracts thermally.

$\Delta_{sMax}$ = Maximum Allowable total shear deformation of the elastomer at service limit state

$$\Delta_{sMax} = \frac{(0.2 - Gr) \times DL \times h_{rt}}{G_0 \times A} \qquad \Delta_{sMax} = 0.619 \cdot \text{in}$$

$\Delta_s = 0.549 \cdot \text{in}$ *(calculated on pg. 4)*

$\boxed{\Delta_{sMax} \text{ is greater tha n } \Delta_s \text{ therefore OK.}}$

If the shear check or the slip check were to fail, break up the unit into smaller pieces to avoid needing a non-standard pad. If you are already committed to a non-standard pad design, try increasing the pad height. For more solutions for slip check failure refer to Appendix A on pg.12.

## Loads (Long Span):

$\mathrm{Span} = 70\ \mathrm{ft}$

$t_{Olay} = 2\ \mathrm{in}$

*Thickness of Overlay*

*The 2" future overlay is considered in the remaining bearing pad design checks, since the greatest load will control these checks.*

### Dead Load:

$$\mathrm{Beam}_{DL} = \mathrm{Wt}_{girder}\cdot\frac{\mathrm{Span}}{2}$$ $\mathrm{Beam}_{DL} = 24.39\cdot\mathrm{kip}$

$$\mathrm{Slab}_{DL} = w_c\cdot t_s\cdot\frac{W_{bridge}}{N_{girder}}\cdot\frac{\mathrm{Span}}{2}$$ $\mathrm{Slab}_{DL} = 26.83\cdot\mathrm{kip}$

$$\mathrm{Olay}_{DL} = w_{Olay}\cdot t_{Olay}\cdot\frac{W_{bridge}}{N_{girder}}\cdot\frac{\mathrm{Span}}{2}$$ $\mathrm{Olay}_{DL} = 6.26\cdot\mathrm{kip}$

$$\mathrm{Rail}_{DL} = \mathrm{Wt}_{rail}\cdot\frac{\mathrm{Span}}{2}\cdot\frac{1}{3\ \mathrm{beams}}$$ $\mathrm{Rail}_{DL} = 4.46\cdot\mathrm{kip}$

*Distribute rail load to a maximum of 3 outer beams (BDM-LRFD Ch. 3, Sect. 5, "Structural Analysis").*

$$\mathrm{DL} = \mathrm{Beam}_{DL} + \mathrm{Slab}_{DL} + \mathrm{Olay}_{DL} + \mathrm{Rail}_{DL}$$ $\mathrm{DL} = 61.95\cdot\mathrm{kip}$

### Live Load:

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

*(AASHTO LRFD 3.6.1.2.2)*

$$\mathrm{Rx}_{Truck} = 62.40\cdot\frac{\mathrm{kip}}{\mathrm{lane}}$$

$$\mathrm{Rx}_{Lane} = 0.64\,\frac{\mathrm{klf}}{\mathrm{lane}}\cdot\frac{\mathrm{Span}}{2}$$ $\mathrm{Rx}_{Lane} = 22.40\cdot\frac{\mathrm{kip}}{\mathrm{lane}}$

*(AASHTO LRFD 3.6.1.2.4)*

$\mathrm{LLDF}_{Shear} = 0.895$

$\mathrm{IM} = 33\ \%$

*(AASHTO LRFD Table 3.6.2.1-1)*

$$\mathrm{LL} = \left[\mathrm{Rx}_{Truck}\cdot(1 + \mathrm{IM}) + \mathrm{Rx}_{Lane}\right]\cdot\mathrm{LLDF}_{Shear}$$ $\mathrm{LL} = 94.33\cdot\mathrm{kip}$

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

### Stresses:

Dead Load Stress:

$$\sigma_d = \frac{\mathrm{DL}}{A}$$ $\sigma_d = 0.369\cdot\mathrm{ksi}$

Live Load Stress:

$$\sigma_L = \frac{\mathrm{LL}}{A}$$ $\sigma_L = 0.561\cdot\mathrm{ksi}$

Total Load Stress at Service:

$$\sigma_s = \frac{\mathrm{LL} + \mathrm{DL}}{A}$$ $\sigma_s = 0.93\cdot\mathrm{ksi}$

## **Compressive Stress Check:** (Service Limit) *(BDM-LRFD Ch. 5, Sect. 2, "Design Criteria")*

$S_i = 11.586$

*(Calculated on pg. 3)*

$\sigma_{dMax}$ = Maximum Allowable Dead Load Stress

$\sigma_{dMax}$ is the smaller of:

$1.2\ \text{ksi}$

$1.2\ G_{73} \cdot S_i = 1.321 \cdot \text{ksi}$

$\sigma_{dMax} = 1.2 \cdot \text{ksi}$

*The 1200 psi dead load stress maximum should not be exceeded by more than 5%, and only if the shape factor permits. For further explanation see Appendix A on pg. 13.*

$\sigma_d = 0.369 \cdot \text{ksi}$

*(Calculated on pg. 6)*

$\sigma_{dMax}$ is greater than $\sigma_d$ therefore OK.

$\sigma_{sMax}$ = Maximum Allowable Service Load Stress

$\sigma_{sMax}$ is the smaller of:

$1.5\ \text{ksi}$

$1.5\ G_{73} \cdot S_i = 1.651 \cdot \text{ksi}$

$\sigma_{sMax} = 1.5 \cdot \text{ksi}$

*The 1500 psi limit, is not an absolute max, and overages of up to 15% above this limit are not cause to resize the pad. For further explanation see Appendix A on pg. 13.*

$\sigma_s = 0.930 \cdot \text{ksi}$

*(Calculated on pg. 6)*

$\sigma_{sMax}$ is greater than $\sigma_s$ therefore OK.

## **Compressive Deflection:** (Service Limit) *(AASHTO LRFD 14.7.6.3.3)*

Compressive deflection is usually not a concern from a functionality standpoint since the 4% to 5% range of deflection that most of TxDOT's standard pads undergo, yields a hardly noticeable 3/32" vertical compression. For further explanation refer to Appendix A on pg.13.

Estimate compressive deflection using AASHTO LRFD Fig. C14.7.6.3.3-1.

*(BDM-LRFD, Ch. 5, Sect. 2, "Design Criteria")*

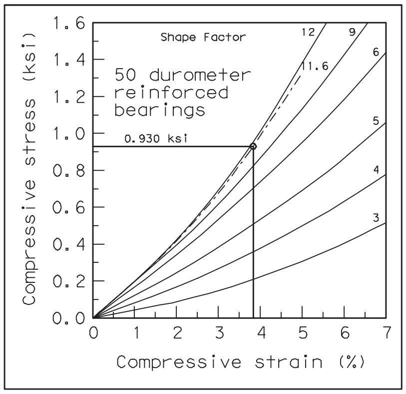
$\sigma_s = 0.930 \cdot \text{ksi}$

*(Calculated on pg. 6)*

$S_i = 11.59$

*(Calculated on pg. 3)*

*Use $S_i$ and $\sigma_s$ to get $\varepsilon_{si}$ from Figure C14.7.6.3.3-1, which can be found in Appendix C on pg.16, Figure C-1.*



*(AASHTO LRFD Fig. C14.7.6.3.3-1)*

$\varepsilon_{si}$ = Elastomer Strain for Service Loading $\varepsilon_{si} = 3.8\ \%$

## **Compressive Deflection:** (Con't)

$\varepsilon_{di}$ = Elastomer Strain for Dead Load

$\varepsilon_{di} = \varepsilon_{si} \dfrac{\sigma_d}{\sigma_s}$ $\varepsilon_{di} = 1.506 \cdot \%$

$\varepsilon_{Li}$ = Elastomer Strain for Live Load

$\varepsilon_{Li} = \varepsilon_{si} \dfrac{\sigma_L}{\sigma_s}$ $\varepsilon_{Li} = 2.294 \cdot \%$

Since all layers in the bearing pad are the same thickness and shape, $\varepsilon_i$ is the same for every layer and therefore the below equations are true.

$\delta_{di}$ = Instantaneous Dead Load Compression Deflection of Elastomer

$\delta_d = \varepsilon_{di} h_{rt}$ $\delta_d = 0.030 \cdot in$ *(AASHTO LRFD Eq. 14.7.5.3.6-2)*

$\alpha_{cr}$ = Creep Deflection Factor $\alpha_{cr} = 0.25$ *(AASHTO LRFD Table 14.7.6.2-1)*

$\delta_{lt}$ = Long Term Compression Deflection of Elastomer

$\delta_{lt} = \delta_d + \alpha_{cr} \delta_d$ $\delta_{lt} = 0.038 \cdot in$ *(AASHTO LRFD Eq. 14.7.5.3.6-3)*

$\delta_L$ = Instantaneous Live Load Compression Deflection of Elastomer

$\delta_L = \varepsilon_{Li} h_{rt}$ $\delta_L = 0.046 \cdot in$ *(AASHTO LRFD Eq. 14.7.5.3.6-1)*

$\delta_s$ = Service Load Compression Deflection of Elastomer

$\delta_s = \delta_{lt} + \delta_L$ $\delta_s = 0.084 \cdot in$

$\delta_{siMax}$ = Maximum Allowable Service Load Compression Deflection of an Interior Layer

$\delta_{siMax} = 0.07 h_{ri}$ $\delta_{siMax} = 0.018 \cdot in$ *(AASHTO LRFD 14.7.6.3.3)*

$\delta_{si}$ = Service Load Compression Deflection of an Interior Layer

$\delta_{si} = \delta_s \dfrac{h_{ri}}{h_{rt}}$ $\delta_{si} = 0.010 \cdot in$

$\delta_{siMax}$ is greater tha n $\delta_{si}$ therefore OK.

## **Rotation:** (Service Limit) *(BDM-LRFD Ch. 5, Sect. 2, "Design Criteria")*

AASHTO has strict guidelines for rotation that TxDOT does not adhere to. AASHTO seeks to prevent any amount of lift off, a requirement that TxDOT does not support. Most TxDOT reinforced elastomeric bearing pads are used under prestressed concrete beams that rotate little (less than 0.005 radians) and impart a fairly heavy dead load on a relatively narrow (9" max) pad, making uplift due to rotation an improbable event. The research for Report 1304-3 has shown rotations close to 0.030 radians can be accommodated by our standard pads with less than 20% lift off, and even with that amount of lift off the pad will function normally. We regularly encounter cases in construction where it is noted that the pad is not in contact with a bearing surface for a considerable portion of the pad area (usually due to construction tolerances, mismatches in surface slopes, etc.) with no apparent detriment to the bearing performance in final service.

***Non-Composite I-Beam Properties:***

E = Modulus of Elasticity of the Beam

$E = 5000\ \text{ksi}$

$I_x$ = Non-Composite Moment of Inertia of the Beam about its strong axis

$I_x = 134990\ \text{in}^4$

*The load due to the Rail and Overlay act on the Composite Cross-Section of the Beam. For simplicity, we will apply all the dead load to the Non-Composite Cross-Section. The Moment of Inertia of the Tx40 girder can be found on the IGD standard.*

q = Total Dead Load of the Superstructure per foot of the beam

$$q = \frac{DL}{\text{Span} \div 2}$$

$q = 1.77 \cdot \text{klf}$

$\theta_{DL}$ = Rotation due to Dead Load

$$\theta_{DL} = \frac{q \cdot \text{Span}^3}{24 \cdot E \cdot I_x} \cdot \left(\frac{12\ \text{in}}{\text{ft}}\right)^2$$

$\theta_{DL} = 0.005 \cdot \text{rad}$

$\text{camber} = 3.552\ \text{in}$

*Use the Camber from PSTRS14 output or PGSuper output*

$\theta_{Camber}$ = Rotation due to Camber

$$\theta_{camber} = \frac{4\ \text{camber}}{\text{Span}} \div \left(\frac{12\ \text{in}}{\text{ft}}\right)$$

$\theta_{camber} = 0.017 \cdot \text{rad}$

*Assuming camber is the result of uniform moment caused by prestressing*

$\Delta_{LL}$ = Midspan Deflection due to Live Load

$$\Delta_{LL} = \frac{\text{Span}}{800} \cdot \left(\frac{12\ \text{in}}{\text{ft}}\right)$$

$\Delta_{LL} = 1.05 \cdot \text{in}$

*Use the LL Midspan deflection from PSTRS14/PGSuper or use the design deflection limit, Span/800, to be conservative.*

$\theta_{LL}$ = Rotation due to Live Load

$$\theta_{LL} = \frac{4\ \Delta_{LL}}{\text{Span}} \div \left(\frac{12\ \text{in}}{\text{ft}}\right)$$

$\theta_{LL} = 0.005 \cdot \text{rad}$

*(BDM LRFD Ch. 5, Sect. 2, "Design Criteria")*

## Rotation: (Con't)

### Rotation due to Downward Deflection of Girder:

$\theta_{camber}$ is greater than $\theta_{DL}$ therefore:

$\theta_{DL\_camber}$ = Rotation due to Dead Load and Camber in the direction of rotation caused by downward applied forces

$\theta_{DL\_camber} = 0 \cdot rad$

*When checking rotations due to downward deflections, the rotation from the combined effects of camber and dead load will not be taken less than zero. This is done to be conservative and because camber is highly variable.*

$\theta$ = Rotation due to maximum downward deflections of beam

$$\theta = \theta_{LL} + \theta_{DL\_camber} + 0.005 \text{ rad}$$

$\theta = 0.010 \cdot rad$

*0.005 radians is added to account for construction uncertainties (AASHTO LRFD 14.4.2.1)*

$\delta_{sMin}$ = Minimum Allowable Service Load Compression Deflection

$$\delta_{sMin} = \frac{\theta\,(0.8\ L)}{2}$$

$\delta_{sMin} = 0.032 \cdot in$

*(BDM LRFD Ch. 5, Sect. 2, "Design Criteria")*

$\delta_s = 0.084 \cdot in$

*(Calculated on pg. 8)*

$\delta_s$ is greater than $\delta_{sMin}$ therefore OK.

### Rotation due to Upward Deflection of Girder:

$\theta$ = Rotation due to maximum upward deflections of beam

$$\theta = \theta_{camber} - \theta_{DL} + 0.005 \text{ rad}$$

$\theta = 0.017 \cdot rad$

*0.005 radians is added to account for construction uncertainties (AASHTO LRFD 14.4.2.1)*

$\delta_{sMin}$ = Minimum Allowable Service Load Compression Deflection

$$\delta_{sMin} = \frac{\theta\,(0.8\ L)}{2}$$

$\delta_{sMin} = 0.053 \cdot in$

*(BDM LRFD Ch. 5, Sect. 2, "Design Criteria")*

$\delta_s = 0.084 \cdot in$

*(Calculated on pg. 8)*

$\delta_s$ is greater than $\delta_{sMin}$ therefore OK.

## Reinforcement Check: (Service Limit)

*(AASHTO LRFD 14.7.6.3.7)*

$h_s = 0.105 \cdot in$

*(From pg. 3)*

$h_{sMin}$ = Minimum Allowable Steel Layer Thickness

$$h_{sMin} = \frac{3\ h_{ri}\ \sigma_s}{F_y}$$

$h_{sMin} = 0.019 \cdot in$

*(AASHTO LRFD Eq. 14.7.5.3.5-1)*

$h_{sMin}$ is smaller than $h_s$ therefore OK.

$\Delta F_{TH}$ = Constant Amplitude Fatigue Threshold

$\Delta F_{TH} = 24\ ksi$

*(LRFD AASHTO Table 6.6.1.2.5-3, Category A)*

$$h_{sMin} = \frac{2\ h_{ri}\ \sigma_L}{\Delta F_{TH}}$$

$h_{sMin} = 0.012 \cdot in$

*(AASHTO LRFD Eq. 14.7.5.3.5-2)*

$h_{sMin}$ is smaller than $h_s$ therefore OK.

# Appendix A

## Unit Information:

*Skew:*

In general, the clipped pad areas do not decrease by more than approximately 10%. The pad plan dimensions were increased when more severe clips were needed. The 10% reduction for clips or the area for dowel holes is not a concern for the following reasons:

1.) Reducing the area of the pad increases the DL stress, thus increasing slip prevention.

2.) The standard bearing pad is typically conservative with regard to allowable compressive stresses.

3.) Shape factor controlled allowable DL compressive stresses vary minimally from the assumptions in the standards due to the altered perimeter to area ratios when clipped.

4.) Compressive deflections are usually around 3/32" for standard pads.

## Bearing Pad Information:

*Bearing Pad Taper:*

Taper is usually not specified by the designer for TxDOT jobs. The fabricators typically extract this information from the contract plans by calculating the beam slope from bearing seat elevations on the bridge "Bearing Seat Elevations and Quantities" sheet. The fabricator then determines which platen satisfies the slope tolerance specifications and can be used in the pad vulcanization process. The standard pads listed on the IBEB sheet will deflect around 4% on average, or about 5/32" for the 2" of elastomer in them, which typically is sufficient to accommodate a slope mismatch from fabrication or construction sources. (5/32" in 9" is equivalent to a slope of 1.74%.)

*Design Recommendations:*

1.) For beams on grades of between 1 and 3%, taper the pads accordingly. The top layer only shall be tapered. (all shims parallel)

2.) For beams on grades of between 3 and 6%, taper the top two layers, limiting the top layer thickness to 3/8" at the thick end. (all shims parallel except top shim)

3.) Beams on grades greater than 6% will require special consideration (ie, span restraints, pad restraints, higher durometer elastomer, custom shim placement, etc.; see Report 1304-3, Chapter 8 for conclusions concerning heavily tapered pads). 6% beam slope is the upper limit that TxDOT will design tapered pads for without special precautions, such as locking the "low" end of the unit in place and forcing the structure to expand uphill.

*Bearing Seat Geometry:*

For custom applications, the designer needs to be aware of the specified minimum cap edge and beam edge distances. The centerline of bearing is a nominal distance and the pads will function satisfactorily if placed off center from it as long as the load is not placed close to a cap edge (which will induce spalling of the cap) or overlapping a beam chamfer edge (which will pinch the elastomer and induce a "walking" phenomena on the cap surface). When checking the required edge distances for custom designs, also take note of the beam end clearance values listed on the standard. Beam end clearance values vary with cap type and are increased on cap types such as inverted tee interior bents, where field experience with construction/fabrication errors and resulting beam end trimming has dictated the need for more room.

*General:*

Continue to "round" layer thicknesses to 1/8" increments within shape factor constraints. Pad width (transverse to beam longitudinal axis) for custom designs should not be less than approximately 3/4 of the bottom beam flange width without a more thorough analysis. TxDOT currently has some exceptions to this guideline - round pads, pads for smaller beams, etc - but have had feedback that in general there have been no construction related stability problems with these particular pads. A general rule of thumb is to design the width of the pad so that the c.g. will always fall within the middle third of the pad. If construction tolerances, i.e. horizontal beam sweep, variance from plumb, out of level bearing seats and so on, can vary the c.g. 4", then the pad should be at least 12" wide.

*Bearing Pad Material:*

TxDOT currently prohibits the use of "Polyisoprene" (Natural Rubber) for the manufacture of bearing pads. This is due to a slip problem experienced in the late 1980's and early 1990's that was caused by a "blooming" of paraffin wax to the surface of the pad. This wax can be used in "Polychloroprene" (Neoprene) but is usually present in much smaller amounts than in natural rubber, and as yet there have been no documented cases of neoprene-associated slip due to a wax bloom in Texas.

## Bearing Pad Slip Check:

*Bearing Pad Slip Failure Fixes:*

Typically slip problems are controlled by increasing the pad thickness. In some cases this may not be desirable from an economic standpoint (fabricator re-tooling) or if the resulting height violates stability criteria. Alternative solutions might include the following:

1) Increase the beam spacing to increase bearing dead load, if the beams can handle the additional load.

2) Increase the end span length if feasible, to increase the compressive stress. The span length should not be increased to the point of requiring an additional beam line. This may not be possible if there are conflicts such as lower roadways, utilities, waterways, etc.

3) Reducing the number of spans in the unit. This is the best choice for standard bridges, as it does not require modified drawings or an in-depth bridge design. For a non-standard bridge, only choose this option if the resulting increase in cost of deck joints does not offset the cost of custom pads. (Standard pads cost approximately $65 to $100 each (FY 2006), custom pads cost almost double the amount of standard ones. Both items usually represent a very small percentage of overall bridge cost and therefore, the decision on which item to purchase is not critical.)

4) As a last resort, decrease the pad plan area to increase slip resistance. The least expensive way to do this is to pick a standard pad from any of our bearing pad standards (IBEB, IGEB, SBEB, BBEB, UBEB, PSBEB, DSBEB, DTBEB). The standard bearing pads are four standard heights (2 3/4" {IBEB, IGEB, SBEB, BBEB}, 2 1/2" {UBEB}, 2" {PSBEB, DSBEB}, and 1 1/4" {DTBEB}); try using a bearing pad that is the same height or taller to satisfy slip. For a Type "Tx40" beam (standard pad: 9" L x 21" W x 2 3/4" h) that fails in slip, try the "IV" pad from the IBEB table (standard pad: 7" L x 22" W x 2 3/4" h). If none of the standard pads solve the problem, design new pad plan dimensions. This requires the fabricator to order new forms or shim for the insides of existing forms, so a large volume job is preferable for this option. When reducing the plan area, do so by decreasing the pad length to preserve pad stability. Construction stability of the beam on the bearing prior to construction bracing installation may be a concern when calculating the pad length reduction. There have been no reports of construction instability associated with relatively narrow pad widths such as that for an AASHTO Type IV beam when using the 15" diameter round pad. Another rule of thumb is to make the pad wide enough so that the center of gravity will never fall outside of the middle third of the pad. This calculation would be based on the designer's estimate of how out of plumb the beam may tilt in the field due to bearing seat construction tolerances, beam fabrication tolerances, beam "warping", etc. In the absence of a more refined approach, the use of existing pad geometries is probably the best solution.

## Compressive Stress Check:

*Allowable Compressive Stresses:*

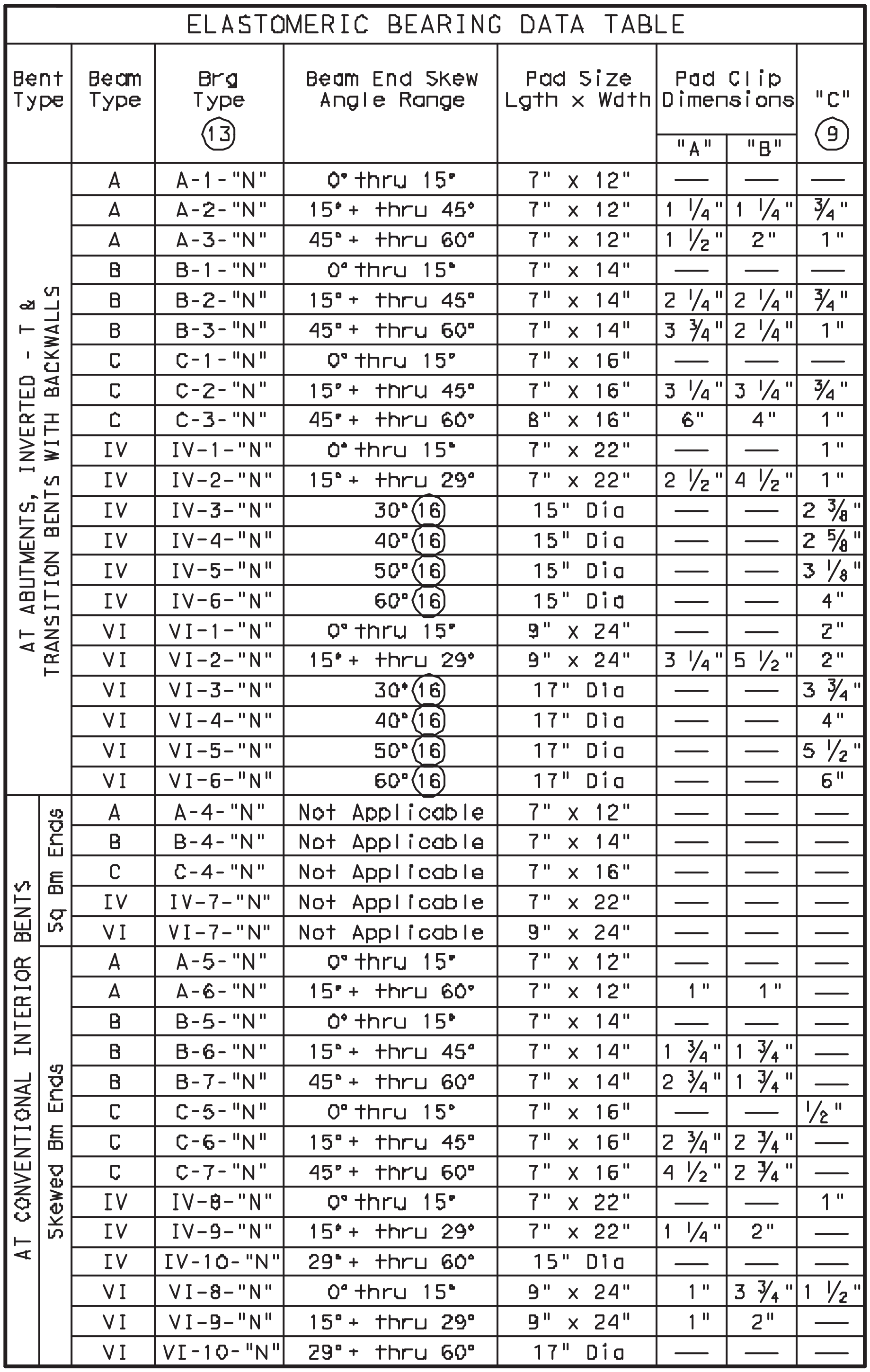
The Service Load check is intended to keep the maximum stresses within a reasonable "range"; it is believed that the temporary nature of a live load has little effect on long term serviceability of the bearing. Thus, the 1500 psi limit, is not an absolute max and overages of up to 15% above this limit are not cause to resize the pad. Reinforced elastomeric bearing pads in the configurations that TxDOT uses have failed in laboratory compression tests at stresses of between 15,000 and 20,000 psi and therefore have large factors of safety against compressive failure. Of greater concern is the loading that the pad sees on a permanent basis, such as under dead load, the consequent side face bulging, and how well the pad functions in combination with cycles of thermally-induced shear strain. For this reason the 1200 psi dead load stress maximum should not be exceeded by more than 5% and only if the shape factor permits. Unlike AASHTO requirements for Method A or Method B, TxDOT design practice places no additional requirement on materials testing when using these allowable compressive stresses. Instead, material quality is insured via prequalification of fabricators, the elastomer formulation and 100% load testing of pads produced for TxDOT.

## Compressive Deflection:

*Compressive Deflection:*

Compressive deflection is usually not a concern from a functionality standpoint, since the 4% to 5% range of deflection that most TxDOT standard pads undergo yields a hardly noticeable 3/32" vertical compression. Severely tapered pads can deflect up to 60% more (close to 5/32" total), but still not enough to induce a "bump" at the end of a bridge. This information becomes useful when determining if a pad can absorb construction mismatches and/or to check rotation ability. Creep will add as much as 25% more deflection, but this is not a concern as it will add a maximum 3/16" total deflection.

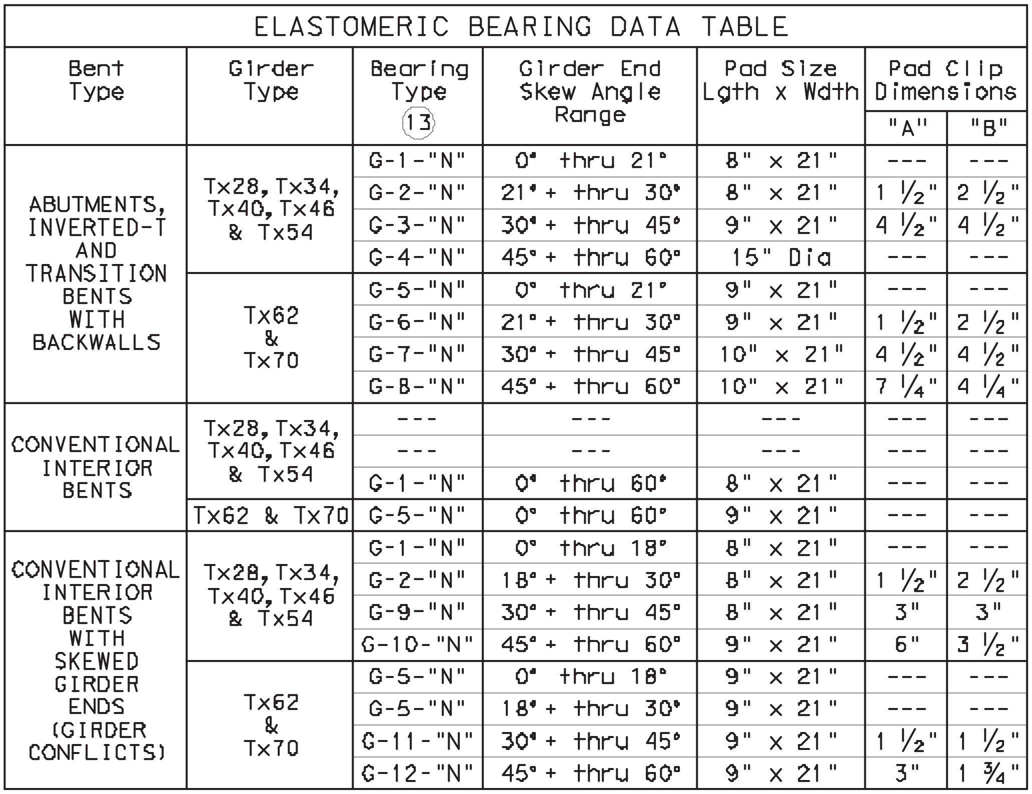
# Appendix B



ELASTOMERIC BEARING DATA TABLE

| Bent Type | | Beam Type | Brg Type ⑬ | Beam End Skew Angle Range | Pad Size Lgth x Wdth | Pad Clip Dimensions "A" | Pad Clip Dimensions "B" | "C" ⑨ |
|---|---|---|---|---|---|---|---|---|
| AT ABUTMENTS, INVERTED - T & TRANSITION BENTS WITH BACKWALLS | | A | A-1-"N" | 0° thru 15° | 7" x 12" | — | — | — |
| | | A | A-2-"N" | 15°+ thru 45° | 7" x 12" | 1 1/4" | 1 1/4" | 3/4" |
| | | A | A-3-"N" | 45°+ thru 60° | 7" x 12" | 1 1/2" | 2" | 1" |
| | | B | B-1-"N" | 0° thru 15° | 7" x 14" | — | — | — |
| | | B | B-2-"N" | 15°+ thru 45° | 7" x 14" | 2 1/4" | 2 1/4" | 3/4" |
| | | B | B-3-"N" | 45°+ thru 60° | 7" x 14" | 3 3/4" | 2 1/4" | 1" |
| | | C | C-1-"N" | 0° thru 15° | 7" x 16" | — | — | — |
| | | C | C-2-"N" | 15°+ thru 45° | 7" x 16" | 3 1/4" | 3 1/4" | 3/4" |
| | | C | C-3-"N" | 45°+ thru 60° | 8" x 16" | 6" | 4" | 1" |
| | | IV | IV-1-"N" | 0° thru 15° | 7" x 22" | — | — | 1" |
| | | IV | IV-2-"N" | 15°+ thru 29° | 7" x 22" | 2 1/2" | 4 1/2" | 1" |
| | | IV | IV-3-"N" | 30° ⑯ | 15" Dia | — | — | 2 3/8" |
| | | IV | IV-4-"N" | 40° ⑯ | 15" Dia | — | — | 2 5/8" |
| | | IV | IV-5-"N" | 50° ⑯ | 15" Dia | — | — | 3 1/8" |
| | | IV | IV-6-"N" | 60° ⑯ | 15" Dia | — | — | 4" |
| | | VI | VI-1-"N" | 0° thru 15° | 9" x 24" | — | — | 2" |
| | | VI | VI-2-"N" | 15°+ thru 29° | 9" x 24" | 3 1/4" | 5 1/2" | 2" |
| | | VI | VI-3-"N" | 30° ⑯ | 17" Dia | — | — | 3 3/4" |
| | | VI | VI-4-"N" | 40° ⑯ | 17" Dia | — | — | 4" |
| | | VI | VI-5-"N" | 50° ⑯ | 17" Dia | — | — | 5 1/2" |
| | | VI | VI-6-"N" | 60° ⑯ | 17" Dia | — | — | 6" |
| AT CONVENTIONAL INTERIOR BENTS | Sq Bm Ends | A | A-4-"N" | Not Applicable | 7" x 12" | — | — | — |
| | | B | B-4-"N" | Not Applicable | 7" x 14" | — | — | — |
| | | C | C-4-"N" | Not Applicable | 7" x 16" | — | — | — |
| | | IV | IV-7-"N" | Not Applicable | 7" x 22" | — | — | — |
| | | VI | VI-7-"N" | Not Applicable | 9" x 24" | — | — | — |
| | Skewed Bm Ends | A | A-5-"N" | 0° thru 15° | 7" x 12" | — | — | — |
| | | A | A-6-"N" | 15°+ thru 60° | 7" x 12" | 1" | 1" | — |
| | | B | B-5-"N" | 0° thru 15° | 7" x 14" | — | — | — |
| | | B | B-6-"N" | 15°+ thru 45° | 7" x 14" | 1 3/4" | 1 3/4" | — |
| | | B | B-7-"N" | 45°+ thru 60° | 7" x 14" | 2 3/4" | 1 3/4" | — |
| | | C | C-5-"N" | 0° thru 15° | 7" x 16" | — | — | 1/2" |
| | | C | C-6-"N" | 15°+ thru 45° | 7" x 16" | 2 3/4" | 2 3/4" | — |
| | | C | C-7-"N" | 45°+ thru 60° | 7" x 16" | 4 1/2" | 2 3/4" | — |
| | | IV | IV-8-"N" | 0° thru 15° | 7" x 22" | — | — | 1" |
| | | IV | IV-9-"N" | 15°+ thru 29° | 7" x 22" | 1 1/4" | 2" | — |
| | | IV | IV-10-"N" | 29°+ thru 60° | 15" Dia | — | — | — |
| | | VI | VI-8-"N" | 0° thru 15° | 9" x 24" | 1" | 3 3/4" | 1 1/2" |
| | | VI | VI-9-"N" | 15°+ thru 29° | 9" x 24" | 1" | 2" | — |
| | | VI | VI-10-"N" | 29°+ thru 60° | 17" Dia | — | — | — |

**Table B-1. Elastomeric Bearing Data from the IBEB Standard**



| ELASTOMERIC BEARING DATA TABLE | | | | | | |
|---|---|---|---|---|---|---|
| Bent Type | Girder Type | Bearing Type ⑬ | Girder End Skew Angle Range | Pad Size Lgth x Wdth | Pad Clip Dimensions | |
| | | | | | "A" | "B" |
| ABUTMENTS, INVERTED-T AND TRANSITION BENTS WITH BACKWALLS | Tx28, Tx34, Tx40, Tx46 & Tx54 | G-1-"N" | 0° thru 21° | 8" x 21" | --- | --- |
| | | G-2-"N" | 21° + thru 30° | 8" x 21" | 1 ½" | 2 ½" |
| | | G-3-"N" | 30° + thru 45° | 9" x 21" | 4 ½" | 4 ½" |
| | | G-4-"N" | 45° + thru 60° | 15" Dia | --- | --- |
| | Tx62 & Tx70 | G-5-"N" | 0° thru 21° | 9" x 21" | --- | --- |
| | | G-6-"N" | 21° + thru 30° | 9" x 21" | 1 ½" | 2 ½" |
| | | G-7-"N" | 30° + thru 45° | 10" x 21" | 4 ½" | 4 ½" |
| | | G-8-"N" | 45° + thru 60° | 10" x 21" | 7 ¼" | 4 ¼" |
| CONVENTIONAL INTERIOR BENTS | Tx28, Tx34, Tx40, Tx46 & Tx54 | --- | --- | --- | --- | --- |
| | | --- | --- | --- | --- | --- |
| | | G-1-"N" | 0° thru 60° | 8" x 21" | --- | --- |
| | Tx62 & Tx70 | G-5-"N" | 0° thru 60° | 9" x 21" | --- | --- |
| CONVENTIONAL INTERIOR BENTS WITH SKEWED GIRDER ENDS (GIRDER CONFLICTS) | Tx28, Tx34, Tx40, Tx46 & Tx54 | G-1-"N" | 0° thru 18° | 8" x 21" | --- | --- |
| | | G-2-"N" | 18° + thru 30° | 8" x 21" | 1 ½" | 2 ½" |
| | | G-9-"N" | 30° + thru 45° | 8" x 21" | 3" | 3" |
| | | G-10-"N" | 45° + thru 60° | 9" x 21" | 6" | 3 ½" |
| | Tx62 & Tx70 | G-5-"N" | 0° thru 18° | 9" x 21" | --- | --- |
| | | G-5-"N" | 18° + thru 30° | 9" x 21" | --- | --- |
| | | G-11-"N" | 30° + thru 45° | 9" x 21" | 1 ½" | 1 ½" |
| | | G-12-"N" | 45° + thru 60° | 9" x 21" | 3" | 1 ¾" |

Table B-2. Elastomeric Bearing Data from the IGEB Standard

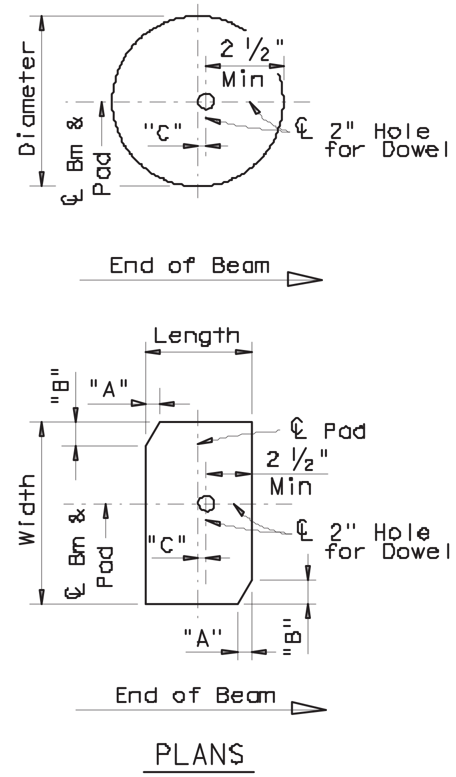


Figure B-1. Bearing Pad Plan Dimentions from the IGEB and IBIB Standards

# Appendix C

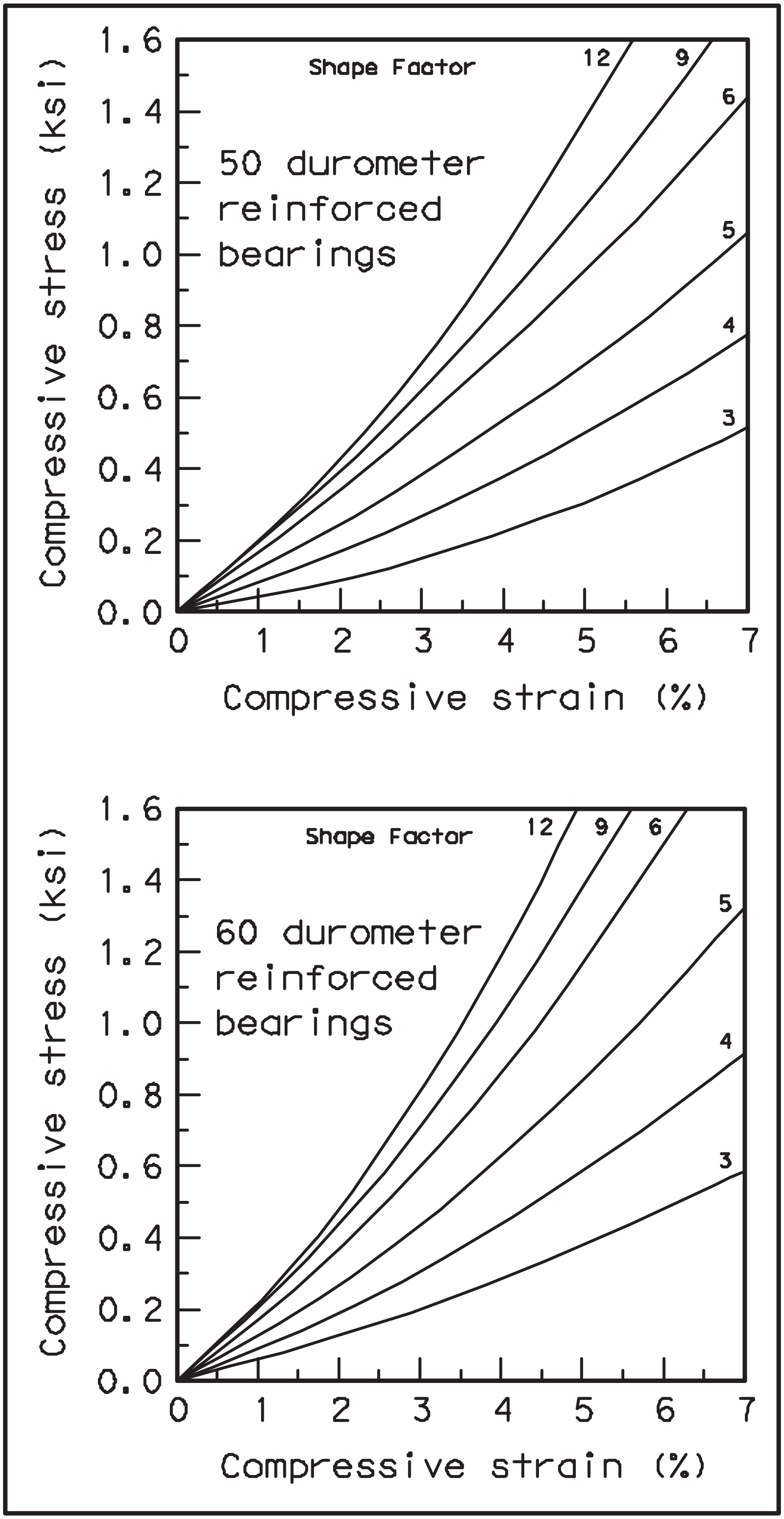


**Figure C-1. Stress-Strain Curves from AASHTO LRFD Fig. C14.7.6.3.3-1**