# AASHTO T-3 TRIAL DESIGN BRIDGE DESCRIPTION

State: *California*

Trial Design Designation: *CA-1*

Bridge Name: *Typical California Bridge used by the Caltrans Design Academy*

Superstructure Type: *Continuous prestressed reinforced concrete box girder*

Span Length(s): *Three span 126ft.-168ft.-118ft.*

Substructure Type: *Two 6.ft. dia. reinforced concrete columns per bent*

Foundation: *Piles*

Abutments: *Seat type supported on piles*

Seismic Design Category (SDC): ______________________

Seismic Design Strategy (Type 1, 2 or 3): ______________________

Design Spectral Acceleration at 1-second Period ($S_{D1}$): ______________________

Additional Description (Optional): ______________________

# I. INTRODUCTION

## I.A. Background/Problem Statement

This prototype bridge is used by various groups teaching the Caltrans Design Academy to illustrate the principles of bridge design including those of seismic design.

This is a three span Prestressed Reinforced Concrete Box Girder bridge. The span lengths are 126 ft, 168 ft and 118 ft. The column height varies from 44 ft at Bent 2 to 47 ft at Bent 3. Both bents have a skew angle of 20 deg. The columns on pinned at the bottom. Figure 1 shows the General Plan for this structure.

## I.B. Bridge Site Conditions

This hypothetical structure crosses a roadway and railroad tracks. Because of poor soil conditions, the footing is supported on piles. The ground motion at the bridge site is assumed to be:

| | |
|---|---|
| Soil Profile: | Type C |
| Magnitude: | $8.0 \pm 0.25$ |
| Peak Rock Acceleration: | 0.5g. |

Figure 2 shows the ARS curve based upon 5% damping as taken from Appendix B of the SDC.

# II. Analysis and Design Procedure

## II.A. Preliminary Member and Span Configuration Determination

Bridge design is inherently an iterative process. It is common practice to design bridges for service loading and then, if necessary, to refine the design of various components to satisfy seismic performance requirements. In reality however, one needs to keep certain seismic requirements in mind even during a service design. This is especially true while selecting the span configuration, column size, column reinforcement requirements, and bent cap width.

<u>Sizing the Column and Bent Cap</u>

- Column Size

According to the SDC (Section 7.6.1), selected column size should satisfy the following criterion

$$0.70 < \frac{D_c}{D_s} < 1.00 \qquad \text{SDC Eqn. (7.24)}$$

Where

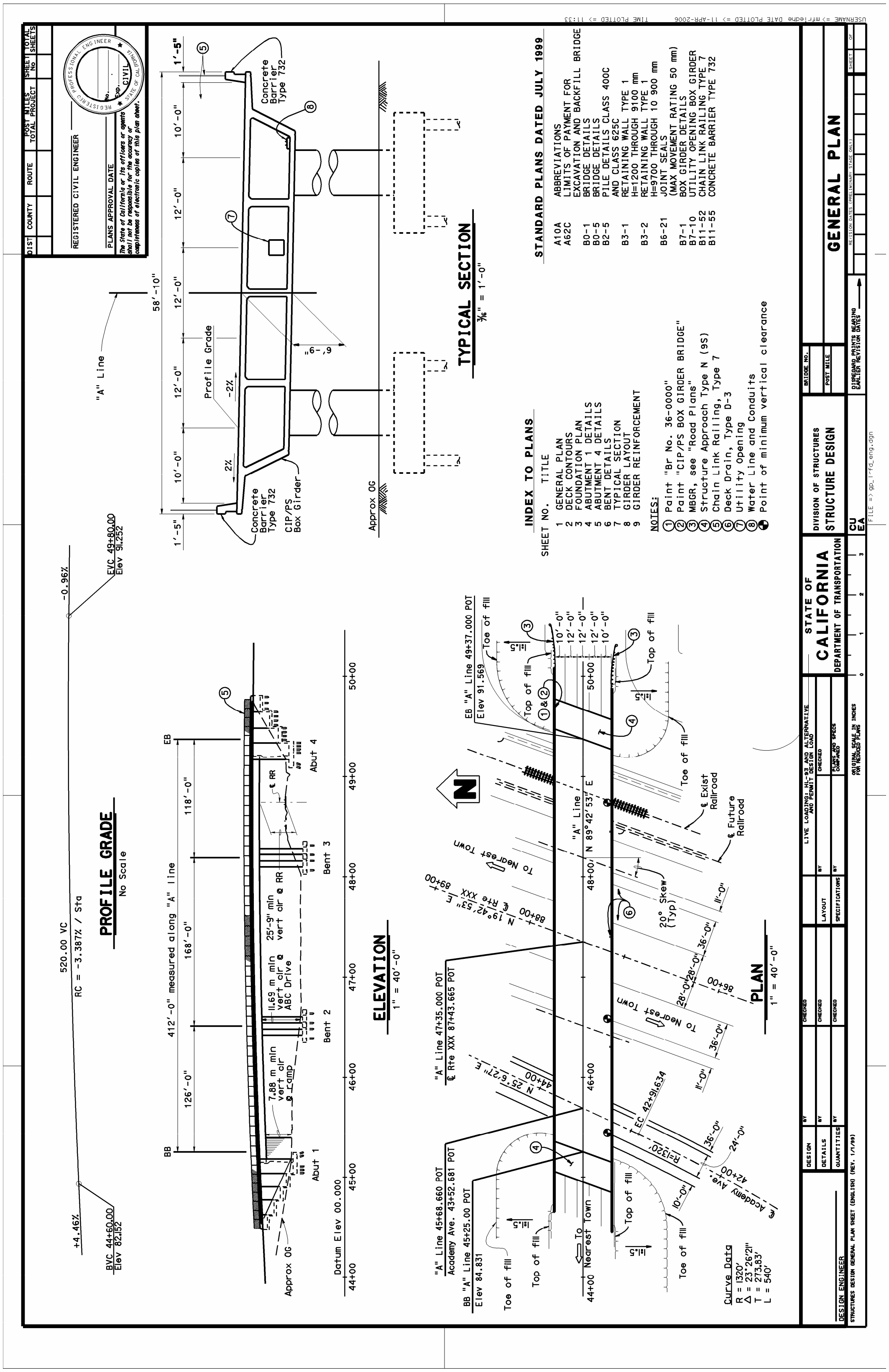



**Figure 1  General Plan (Bridge Design Academy Prototype Bridge)**

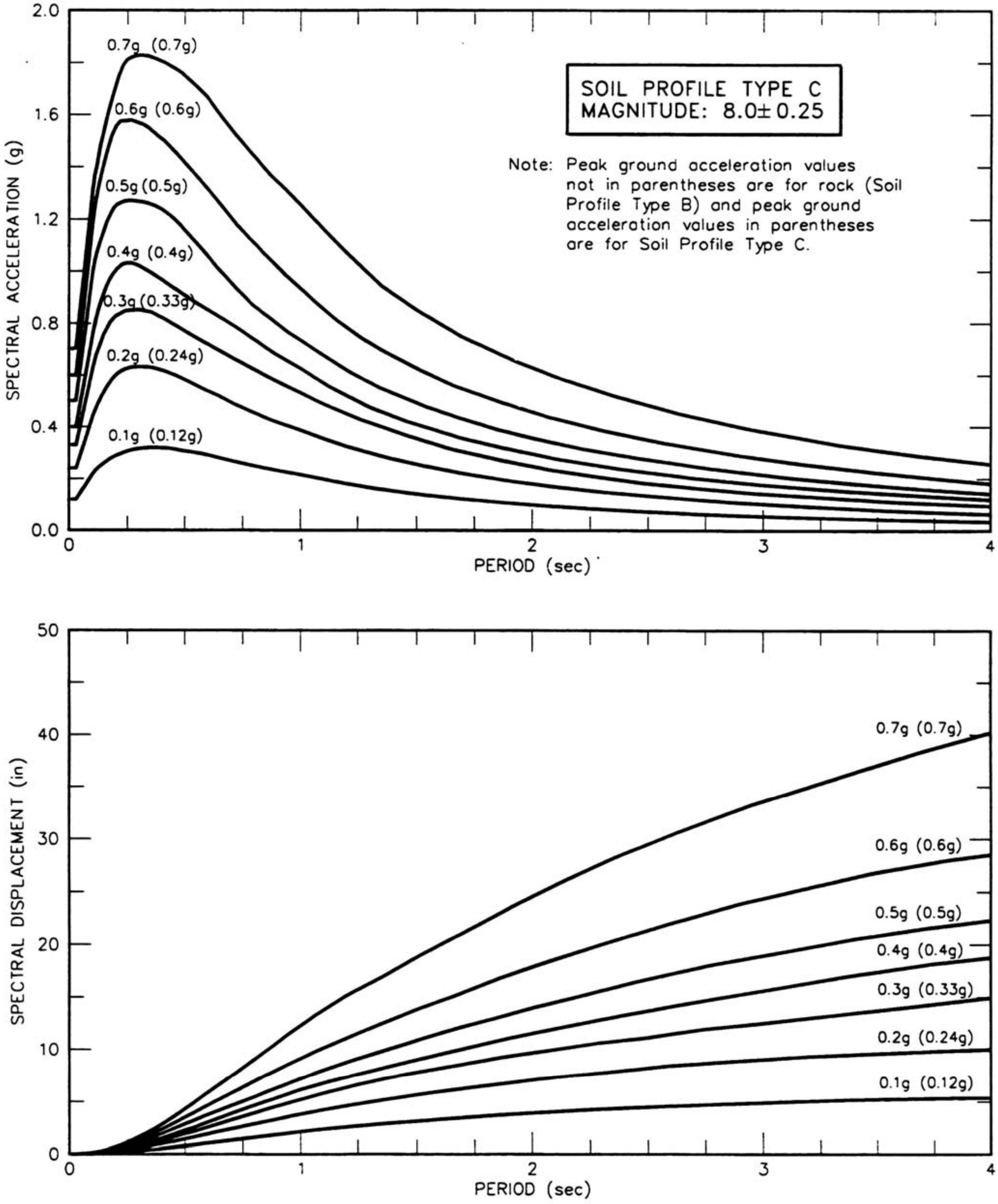



**Figure 2 Response Spectrum Curves For Soil Profile C ($M$ = 8.0±0.25)**
**(See SDC Figure B.6)**

$D_c$ = Column diameter

$D_s$ = Superstructure depth

If $D_c > D_s$, it may be difficult to meet the joint shear, superstructure capacity, and ductility requirements.

Given $D_s = 6.75$ ft from the service design, we select a column with $D_c = 6.00$ ft so that $D_c / D_s = 0.89$.

Max. Longitudinal Reinforcement Area, $A_{s\,\max} \leq 0.04 \times A_g$ SDC Eqn.(3.28)

Min. Longitudinal Reinforcement Area, $A_{s\,\min} \geq 0.01 \times A_g$ SDC Eqn.(3.29)

where $A_g$ is the gross cross sectional area.

Normally choosing 1.5% main steel is a good starting point.

$$A_s = 0.015 \times A_g = 0.015 \times \frac{\pi}{4}(6.00 \times 12)^2 = 61.07 \text{ in}^2$$

Either spirals or hoops can be used as transverse (lateral) reinforcement in the column. However, according to Memo-To-Designers 20-6, hoops are preferred because of their discrete nature in case of local failure. The amount of transverse reinforcement expressed as volumetric ratio

$$\rho_s = \frac{4 \times A_b}{D' \times s} \text{ for circular columns} \qquad \text{SDC Eqn. (3.31)}$$

$A_b$ = Area of transverse reinforcing hoop/spiral rebar

$D'$ = Concrete section core diameter

$s$ = Transverse reinforcement spacing

shall be sufficient to ensure that the column meets the performance requirements as specified in SDC Section (4.1). Additionally, such reinforcement should also meet the volumetric ratio requirements of BDS Equation (8-62) and the column shear requirements as specified in SDC section (3.6.3).

The selected bar layout should satisfy the following spacing requirements for effectiveness and for constructability:

- Longitudinal Reinforcement

  Maximum Spacing = 8 in BDS Section (8.21.1.2)

  Minimum Spacing requirements are summarized in BDS Section (8.21.1)

- Transverse Reinforcement

According to the SDC Section (8.2.5) and BDS Section (8.21.1.1), the maximum spacing in the plastic hinge region shall not exceed the smaller of:

- 1/5 of the column dimension (14.4 in), for confinement.
- 6 times the diameter of the longitudinal bars (10.2 in), to prevent longitudinal bar buckling.
- 8 in.

Keeping these requirements in mind, let us use the following reinforcement:

- #14 bars for longitudinal reinforcement
- #8 hoops @ 5 in c/c for the plastic hinge region. Outside this region, the hoop spacing can be and should be increased to economize the design.

Assume a concrete cover of 2 in (BDS Table 8.22.1)

$d_M$ = Dia. of the longitudinal reinforcement loop

$$= 72 - 2\times 2 - 2\times 1.13 - \frac{1.88}{2} - \frac{1.88}{2} = 63.86 \text{ in}$$

Number of #14 bars = $\dfrac{61.07}{2.25} = 27.1$

Let us use 26, #14 bars (1.44%) so that

$$\text{Spacing} = \frac{\pi \times d_M}{26} = 7.7 \text{ in}$$

which meets the maximum spacing requirements outlined above. If the provided spacing turns out to be more that the maximum spacing allowed, then a smaller bar size can be used.

<u>Selecting Bent Cap Width</u>

This prototype bridge has an integral bent cap. The depth of such a bent cap is the same as the depth of the superstructure. According to SDC ( Section 7.4.2.1), the minimum cap width that is required for adequate joint shear transfer is specified as

$B_{cap} = D_c + 2$ (ft) SDC Eqn. (7.10)

For our case, the bent cap width shall be 6 + 2 = 8 ft.

## II.B Balanced Stiffness Check and Preliminary Demand Assessment

For an acceptable seismic response, a structure with well-balanced mass and stiffness across various frames is highly desirable. Such a structure is likely to respond to a seismic activity in a simple mode of vibration and any structural damage will be well distributed among all the columns. The best way to increase the likelihood that the structure responds in its simplest fundamental mode is to balance its stiffness and mass distribution. To this end, the SDC recommends that the ratio of effective stiffness between *any* two bents within a frame or between *any* two columns within a bent satisfy:

$$\frac{k_i^e \times m_j}{k_j^e \times m_i} \geq 0.5 \qquad \text{SDC Eqn.(7.1b)}$$

The SDC further recommends that the ratio of effective stiffness between *adjacent* bents within a frame or between *adjacent* columns within a bent satisfy SDC equation 7.2:

$$\frac{k_i^e \times m_j}{k_j^e \times m_i} \geq 0.75 \qquad \text{SDC Eqn. (7.2b)}$$

$k_i^e =$ Smaller effective bent or column stiff. $m_i =$ Tributary mass on column or bent *i*.

$k_j^e =$ Larger effective bent or column stiff. $m_j =$ Tributary mass on column or bent *j*.

Bent stiffness should also include the effects of foundation flexibility if it is determined to be significant by the geotechnical engineer.

It should be noted that SDC Equations (7.1a) and (7.2a) are just special cases of Equations (7.2b) and (7.1b) and are used when the mass distribution across bents and columns is uniform. Most of the time, because of variable-width superstructures this is not the case. Therefore, it is suggested that the more general equations should be used.

If these requirements of balanced effective stiffness are not met, some of the consequences include:

- The stiffer bent or column will attract more force and hence will be susceptible to increased damage.
- The inelastic response will be distributed non-uniformly across the structure.
- Increased column torsion demands will be generated by rigid body rotation of the superstructure.

In order to apply this check, we need to calculate the effective stiffness and tributary mass at each bent.

**Balanced Frame Geometry**

It is strongly recommend that the ratio of fundamental periods of vibration for adjacent frames in the longitudinal and transverse direction satisfy equation 7.3.

$$T_i / T_j \geq 0.7 \qquad \text{SDC Eqn (7.3)}$$

$T_i$ = Natural period of the stiffer frame

$T_j$ = Natural period of the flexible frame

The consequences of not meeting the fundamental period requirements of equation 7.3 include a greater likelihood of out-of-phase response between adjacent frames leading to large relative displacements that increase the probability of longitudinal unseating and collision between frames at the expansion joints.

The computer program, *xSECTION* is used to estimate the column effective section properties as well as the Moment-Curvature ( $M-\phi$ ) relationship that will be needed later on to estimate member ductility.

As a first step towards calculating effective section properties for the column, the dead load axial force at column top (location of potential plastic hinge) is calculated. These column axial forces are obtained from the CTBridge output. Appendix A lists selective CTBridge input data. Selective output from this CTBridge run is given in Appendix B. These dead load axial forces include self-weight of the box girder, Type 732 concrete barrier, and weight of the future wearing surface (35 psf). The concrete unit weight used is 150 lb/ft$^3$. It should also be noted that these loads do not include weight of the integral bent cap. The CTBridge model has the regular superstructure cross-section with flared bottom slab instead of solid cap section. To be exact, only the weight of extra concrete should be added to the CTBridge output values to account for the full bent cap weight. The weight of whole solid cap was added to the CTBridge results (conservative).

As read from the CTBridge output results, the column dead load axial forces are:

| | Column 1 | Column 2 |
|---|---|---|
| Bent 2 ($P_c$) | 1,489 kips | 1,494 kips |
| Bent 3 ($P_c$) | 1,425 kips | 1,453 kips |

$$\text{Average Bent Cap Length} = \frac{\textit{Deck Width} + \textit{Soffit Width}}{2} \times \frac{1}{\cos(\textit{Skew Angle})}$$

$$\text{Average Bent Cap Length} = \frac{49.83 + 43.08}{2} \times \frac{1}{\cos(20^0)} = 49.44\, ft\ .$$

$$\text{Bent Cap Weight} = 8 \times 6.75 \times 49.44 \times 0.150 = 400\ kips$$

Adding this bent cap weight, total axial force in each column becomes:

| | Column 1 | Column 2 |
|---|---|---|
| Bent 2 ($P_c$) | 1,689 kips | 1,694 kips |
| Bent 3 ($P_c$) | 1,625 kips | 1,653 kips |

Efforts should be made to keep the dead load axial forces in columns around 10% of their ultimate compressive capacity, $P_u = A_g \times f_c'$. This is recommended to make sure that column does not experience brittle compression failure and also that any potential $P-\Delta$ effects remain within acceptable limits. In our case, axial forces are about 10% of such ultimate compressive capacity. When this ratio starts approaching 15%, increasing column size or adding extra column should be considered.

Material and Effective Column Section Properties ($I_e$)

Material Properties

- Concrete

As per Caltrans common design practice, $f_c^{'} = 4{,}000\ psi$ is used for superstructure, columns, piers, and pile shafts. For other components like abutments, wingwalls, and footings, use of $f_c^{'} = 3{,}600\ psi$ is specified.

As per SDC Section (3.2), expected material properties are to be used to calculate section capacities for all ductile members. To be consistent between the demand and capacity, expected materials will also be used to calculate member stiffness. For concrete, the expected yield strength, $f_{ce}^{'}$, is taken as

$$f_{ce}^{'} = Greater\ of \begin{pmatrix} 1.3 \times f_c^{'} \\ 5{,}000\ psi \end{pmatrix} \qquad \text{SDC Eqn. (3.13)}$$

In our case,

$f_{ce}^{'} = 1.3 \times 4{,}000 = 5{,}200\ psi\ >\ 5{,}000\ psi$ will be used.

Other concrete properties used are listed in SDC section (3.2.6).

- Steel

Grade A706/A706M will be used for reinforcing bar steel. The material properties for such steel are given in SDC Section (3.2.3).

It is well known that concrete cover spalls off at very low ductility levels. Therefore, the effective (cracked) moment of inertia values will be used to assess the seismic response of all ductile members.

Currently, *xSECTION* works in English Units only. The following equivalent English Unit values for the column section, and the concrete and steel properties are used as input to this program:

- Column Dia. = 72.0 in
- Concrete Cover = 2 in
- Main Reinforcement: #14 bars, tot. 26.
- Lateral Reinforcement: #8 hoops @ 5 in c/c.
- $f'_{ce} = 5{,}200\, psi$
- The program calculates the modulus of elasticity of concrete internally.

  $E_s = 29{,}000\ ksi$
- $f_{ye} = 68\ ksi$

  $f_{ue} = 95\ ksi$

- $\varepsilon_{su}^{R} = \begin{pmatrix} 0.09 \\ 0.06 \end{pmatrix} \begin{matrix} \textit{Transverse} & \textit{Steel} \\ \textit{Longitudinal} & \textit{Steel} \end{matrix}$

Bent 2 Column Axial Force, $P_c$=1,694 kips.

Bent 3 Column Axial Force, $P_c$=1,653 kips.

Using these section and material properties, a section analysis is now performed using *xSECTION* program.

- An input file to *xSECTION* for the Bent 2 Column is shown in Appendix C. An input file for Bent 3 Column will be similar except for different column axial loads.

- Output for this *xSECTION* run is shown in Appendix D.

- Moment-Curvature ($M - \phi$) diagram for Bent 2 Column is shown in Appendix E.

For a single pinned-fixed column, the lateral bending stiffness is given as

$$k_2^e = \frac{3 \times E_c \times I_e}{L^3}$$

L = Column height, measured from the pin at top of footing to the soffit of the bridge (SDC 3.1.3)

The concrete modulus of Elasticity, $E_c$, is given by

$$E_c = 33 \times \left(w_c\right)^{1.5} \times \sqrt{f_c^{'}} \ (psi)$$ SDC Eqn. (3.11)

where $w_c$ is the unit weight of concrete in Kg/m$^3$. Using expected value of $f_c^{'}$,

$$E_c = \left[\frac{33 \times \left(150\right)^{1.5} \times \sqrt{5{,}200}}{1{,}000}\right] = 4{,}372 \ ksi$$

- Bent 2 Stiffness

From the $M - \phi$ analysis results, the cracked moment of inertia, $I_e =$ 23.717 ft$^4$ (See Appendices D and E).

$$k_2^e = (2Columns)\left[\frac{(3) \times (4{,}372) \times (23.717) \times (12^4)}{(44 \times 12)^3}\right]$$

or $$k_2^e = 87.64 \ \frac{k}{in}$$

- Bent 3 Stiffness

Again from $M - \phi$ analysis results, $I_e =$ 23.612 ft$^4$

$$k_3^e = (2Columns)\left[\frac{(3) \times (4{,}372) \times (23.612) \times (12^4)}{(47 \times 12)^3}\right]$$

or $$k_3^e = 71.59 \ \frac{k}{in}$$

Total tributary mass at Bent 2 = $\frac{(2Columns) \times (1{,}694)}{(32.2) \times (12)} = 8.77 \ kips - s^2 / in$

Total tributary mass at Bent 3 = $\frac{(2Columns) \times (1{,}653)}{(32.2) \times (12)} = 8.56 \ kips - s^2 / in$

$$\frac{k_i^e \times m_j}{k_j^e \times m_i} = \frac{(71.59) \times (8.77)}{(87.64) \times (8.56)} = 0.84$$ OK

***Therefore, the current span layout configuration satisfies the SDC balanced stiffness criteria for adjacent bents in a frame.***

*The columns within each bent are of the same height and they support equal gravity loads, thus SDC Equation (7.1) is automatically satisfied.*

As mentioned earlier, if foundation flexibility is significant, its effect must be considered while performing these checks.

In case the bents/frames do not meet the SDC requirements for balanced stiffness, one or more of the following techniques (SDC 7.1.3 ) can be considered for adjusting the fundamental period of vibration:

- Use of oversized shafts.
- Adjust the effective column length. Examples include lowering footings, using isolation casings.
- Modify end fixities.
- Redistribute superstructure mass.
- Vary column size and/or longitudinal reinforcement.
- Add or relocate columns.
- Modify the hinge/expansion joint layout, if applicable.
- Use isolation bearings or dampers.

If the column reinforcement exceeds the preferred maximum, the following additional revisions as outlined in MTD 6-1 may help:

- Pin columns in multi-column bents and selected single columns at base adjacent to abutments.
- Use higher strength column concrete.
- Shorten spans and add bents.
- Use pile shafts in lieu of footings.
- Add more additional columns per bent.

Before we proceed with a comprehensive analysis to consider the effects of change in columns axial forces due to seismic overturning moments and also the effects of soil overburden on column footings, let us now check the component ductility capacity requirements for ductile members to make sure that basic SDC ductility requirements are met. These ductility calculations are based upon section 3.1 of the SDC. It is Caltrans practice to use an idealized bilinear $M-\phi$ curve to estimate the idealized yield displacement and deformation capacity of ductile members.

<u>Bent 2</u>

L=44 ft.
$\phi_Y = 0.000078\ rad/in$ as read from the $M-\phi$ data listed in Appendix D.

The analytical plastic length, $L_p$, is estimated using SDC Eqn. (7.25) as

$$L_p = 0.08\times L + 0.15\times f_{ye}\times d_{bl} \geq 0.3\times f_{ye}\times d_{bl}$$

With L=528 in, $f_{ye}$=68 ksi, and $d_{bl}$=1.693 in,

$$L_p = 0.08\times 528 + 0.15\times 68\times 1.693 = 59.51\,in > (0.3\times 68\times 1.693) = 34.54 \text{ in.}$$

$$\therefore L_p = 59.51 \text{ in.}$$

The idealized column yield displacement is now calculated

$$\Delta_Y = \frac{1}{3}\times(528)^2\times 0.000078 = 7.25 \text{ in.}$$

Plastic curvature, $\phi_p = 0.000747$ rad/in as read from the $M-\phi$ data shown in Appendices D and E.
Plastic rotation, $\theta_p = L_p\times\phi_p = 59.51\times 0.000747 = 0.044454$ rad.
Plastic displacement, $\Delta_p = 0.044454\times\left(528-\frac{59.51}{2}\right) = 22.15$ in.
Total Displacement Capacity, $\Delta_c = 7.25+22.15 = 29.40$ in.

Local Displacement Ductility Capacity for Bent 2 Columns is now calculated as

$$\mu_c = \frac{\Delta_c}{\Delta_Y} = \left(\frac{29.40}{7.25}\right) = 4.1 > 3 \qquad \text{SDC Eqn. (3.6)} \qquad \text{OK.}$$

Similarly, for Bent 3 Columns

$$\mu_c = \frac{\Delta_c}{\Delta_Y} = \left(\frac{33.20}{8.27}\right) = 4.0 > 3 \qquad \text{SDC Eqn. (3.6)} \qquad \text{OK.}$$

***Thus, the column section size and reinforcement meets the local displacement ductility capacity requirements of the SDC.***

<u>Displacement Demand</u>

As a preliminary step, the seismic demand can be estimated using Elastic Static Analysis (ESA). This method is most suitable for structures with well balanced spans and uniformly distributed stiffness where the response can be captured by a simple predominantly translational mode of vibration:

For Bent 2

The period of fundamental mode of vibration, $T_2$, is calculated as

$$T_2 = 2\pi\sqrt{\frac{m_2}{k_2^e}} = 2\pi\sqrt{\frac{8.77}{87.64}} = 1.99 \text{ sec.}$$

Similarly, for Bent 3,

$T_3 = 2.17$ sec. The longer period is expected because the Bent 3 columns are taller and support more gravity load.

From the ARS curve shown in Figure 2, the values of spectral acceleration for two bents are read to be

$$a_2 = 0.36\ g$$
$$a_3 = 0.33\ g$$

The displacement demand can now be estimated as

$$\Delta_D = \frac{m \times a}{k_e}$$

For Bent 2 Columns,

The displacement demand, $\Delta_D = \dfrac{8.77 \times 0.36 \times 32.2 \times 12}{87.64} = 13.92$ in.

The displacement demand ductility, $\mu_D = \dfrac{13.92}{7.25} = 1.9 \le 5$ OK SDC Section (2.2.4)

Also $\Delta_D = 13.92\ in < \Delta_C = 29.40\ in$ OK SDC Equation (4.1)

Similarly, for Bent 3 Columns,

The displacement demand, $\Delta_D = \dfrac{8.56 \times 0.33 \times 32.2 \times 12}{71.59} = 15.25$ in.

The displacement demand ductility, $\mu_D = \dfrac{15.25}{8.27} = 1.8 \le 5$ OK SDC Section (2.2.4)

Also $\Delta_D = 15.25\, in < \Delta_C = 33.20\, in$ OK SDC Equation (4.1)

# II.C. Transverse Pushover Analysis and Design

## II.C.1 Modeling Assumptions Including Soil Springs

During the transverse movement of a multi-column frame, a strong cap beam provides a framing action. As a result of this framing action, the column axial force can vary significantly from the dead load state. If the seismic overturning forces are large, the top of the column might even go into tension. The cap beam is not infinitely rigid. The flexibility provided by the bent cap alters the column end condition. Also, the effect of soil-structure interaction can be included . Such effect can be significant in the case where footings are buried deep in the ground.

Push over is mainly a capacity estimating procedure but it can also be used to estimate demand for structures having characteristics outlined previously. The computer program *wFRAME* is used to perform pushover analysis with the following conventions:

- The model is two dimensional with beam elements along the center of cap beam and columns.

- The dead load of superstructure, bent cap, and of columns, if desired, is applied as a uniformly distributed load along the length of the bent cap.

- The element connecting the superstructure c.g. to the column end point at the soffit level is modeled as a super stiff element with stiffness that is two times higher than the regular column section. The moment capacity used for such element is also two times the plastic moment capacity of the column. This is done to ensure that for a column-to-superstructure fixed connection, the plastic hinge forms at top of the column but below the soffit.

    - The soil effect is included as $p-y$ springs applied to the column portion below the ground. The data used for this site is shown in Appendix F.

Figure 3 on the following page schematically shows such a model.

The following values of effective section properties and idealized column plastic moment capacity (under dead loads only) are used as input to *wFRAME* program for pushover analysis.

| $P_c(kips)$ | $M_p(ft-kips)$ | $I_e(ft^4)$ | $\phi_Y(rad/in)$ | $\phi_p(rad/in)$ |
|---|---|---|---|---|
| 1,694 | 13,838 | 23.717 | 0.000078 | 0.000747 |

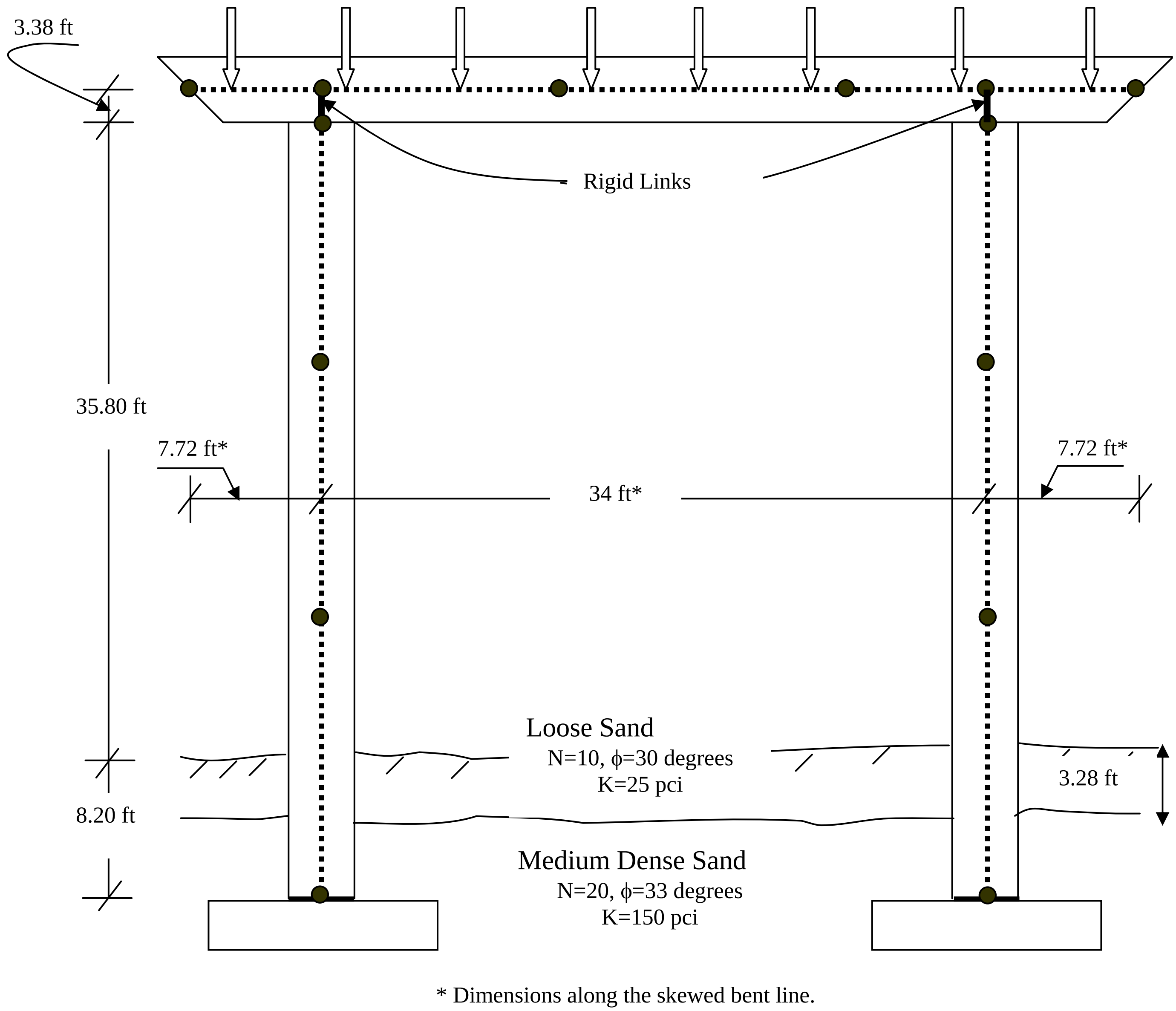



**Figure 3 Transverse Pushover Analysis Model**

The effective bent cap width is calculated as per SDC 7.3.1.1. The Appendix G shows the *xSECTION* model of the bent cap. The Appendices H1 and H2 show selective portions of *xSECTION* output showing cap section properties for positive and negative bending. The following section properties are used

$A = 62.62 \ ft^2$

$$I_{eff}^{+ve} = 55.57 \ ft^4$$
$$I_{eff}^{-ve} = 48.94 \ ft^4$$

As required by the SDC, capacity protected concrete components such as the bent cap, superstructure and footing shall be designed to remain essentially elastic when the column reaches its overstrength capacity. This is required in order to make sure that no plastic hinge forms in these components. The SDC requires that the bent cap flexure and shear capacity equals or exceeds the demand imposed by the column overstrength moment. Appendix I lists *wFRAME* input file.

As the frame is pushed toward the right, the resulting overturning moment causes redistribution of the axial forces in the columns. This overturning causes an additional axial force on the front side column which will experience additional compression. The column on the back side experiences the same value in tension, reducing the net axial load. Based upon their behavior, these columns are usually known as compression and tension columns, respectively.

At the instant when the first plastic hinge forms (in this case at the top of the compression column), the superstructure displacement and corresponding lateral force values are obtained from *wFRAME* output. Appendix J shows *wFRAME* output.

$$\Delta_y = 8.49 \ in$$
$$F_y = 0.171 \times (3{,}382) = 578 \ kips$$
where 3,382 lb is the total tributary weight on the bent.

At this stage, the axial forces in tension and compression columns as read from the *wFRAME* analysis output are 907 kips and 2,474 kips, respectively. These values can be quickly checked using simple hand calculations as described below:

$$M_{overturning} = 578 \times 44 = 25{,}432 \ ft - kips.$$

The axial compression corresponding to such overturning is given as

$$\Delta P = \pm \frac{25{,}432}{34} = 748 \ kips$$

The axial force in the compression column will increase to $1{,}694 + 748 = 2{,}442 \ kips$ . The tension column will see its axial compression drop to $1{,}694 - 748 = 946 \ kips$ . These values compare very well with the *wFRAME* results. Small differences are probably due to the presence of soil in the more realistic *wFRAME* model.

Now we know that the overturning caused by seismic forces results in significant change in the column axial forces. We also know that the effective section properties and column yield moments are influenced by the level of axial force. Therefore, for these updated axial forces, the section properties are calculated again using *xSECTION*. See Appendix K for these results.

| Column Type | $P_c(kips)$ | $M_p(ft-kip)$ | $I_e(ft^4)$ | $\phi_Y(rad/in)$ | $\phi_p(rad/in)$ |
|---|---|---|---|---|---|
| Tension | 907 | 12,636 | 21.496 | 0.000079 | 0.000836 |
| Compression | 2,474 | 14,964 | 25.572 | 0.000079 | 0.000682 |

Note that higher compression produces a higher value of $M_P$ but a reduction in $\phi_P$. This trend occurs in all columns and is a reminder that $M_P$ is not the only indicator of column performance.

The effect of change in the axial force in a column section due to overturning moments can be summarized as below:

- $M_P$ changes
- The tension column has become more ductile while the compression column has become less ductile.
- The required flexural capacity of cap beam that is needed to make sure that the hinge forms at column top is now obviously larger.

With updated values of $M_P$ and $I_e$, we run a second iteration of the *wFRAME* model. As the frame is pushed laterally, the compression column yields at the top. The tension column has not reached its capacity yet. See Appendix L for these results. At this moment,

$\Delta_{y(1)} = 8.79\ in$

At this stage, the column axial forces are read to be 880 kips, 2,502 kips for tension and compression columns, respectively. Since, the change in column axial load is now less than 5%, there is no need for further iteration.

As iteration 2 is pushed further, the already yielded compression column is able to undergo additional displacement because of its plastic hinge rotational capacity. As the bent is pushed further, the top of the tension column yields. At this point the effective bent stiffness approaches zero and will not attract any additional force if pushed further. The bent, however, will be able to undergo additional displacement until the rotational capacity of one of the hinges is reached. Appendix L shows selective portions of the *wFRAME* output file. The Force-Displacement relationship is shown in Appendix M.

$\Delta_{y(2)} = 10.52\ in.$ This is an updated value of the idealized yield $\Delta_Y$ which was calculated previously based upon the assumption that cap beam is infinitely rigid.

$F_{y(2)} = 0.190 \times (3{,}382) = 643\ kips$

## II.C.2.i Displacement Capacity and Demand

Using the procedure already described on page 12 to calculate the plastic deformation and using the section properties listed above, the section capacities for both columns are calculated to be

<u>Tension Column</u>

$$L_p = 59.51\, in$$

$$\Delta_p = 24.79\ in$$

$$\Delta_c = 10.52 + 24.79 = 35.31\, in$$

$$\mu_c = \frac{35.31}{10.52} = 3.4$$

<u>Compression Column</u>

$$L_p = 59.51\, in$$

$$\Delta_p = 20.22\ in$$

$$\Delta_c = 8.79 + 20.22 = 29.01\, in$$

$$\mu_c = \frac{29.01}{8.79} = 3.3$$

For bents having a larger number of columns or more locations for potential hinging, tabulation of these results provides a quick way to determine the critical hinge.

| Hinge Location | Yield Displacement (in) | Plastic Deformation (in) | Total Displacement Capacity (in) |
|---|---|---|---|
| Compression Column Top | 8.79 | 20.22 | 29.01* |
| Tension Column Top | 10.52 | 24.79 | 35.31 |

* Critical bent displacement capacity, $\Delta_C$. The bent capacity calculated previously on page 12 was to size up the members before proceeding with more realistic and comprehensive analysis that includes the effects of bent cap flexibility.

<u>Estimating the Seismic Demand</u>

The effective bent stiffness is estimated as

$$k_2^e = \frac{F_y}{\Delta_y} = \frac{643}{10.52} = 61.12\ \frac{k}{in}$$

and the period of vibration, T, is calculated to be

$$T = 2\pi \times \sqrt{\frac{8.77}{61.12}} = 2.4\sec$$

From the ARS curve, the spectral acceleration $a_2$ is read to be 0.30 g. The maximum seismic displacement demand is estimated as

$$\Delta_d = \frac{8.77 \times (0.30 \times 32.2 \times 12)}{61.12} = 16.63\, in$$

$$\mu_d = \frac{16.63}{10.52} = 1.6 < 5 \qquad \text{SDC Section (2.2.4)}$$

and also $\Delta_d = 16.63\, in < \Delta_c = 29.01\, in.$ SDC Equation (4.1)

Note that the bent is forced well beyond its yield displacement but that collapse is prevented because of ductile capacity. This is what we expect out of the Caltrans "No Collapse" Performance Criteria. Based upon these checks one might conclude that the column is over designed for the anticipated seismic demand. However, as shown little bit later in section II.C.2.ii, the so-called $P-\Delta$ controls the column flexural design.

The same procedure is then repeated to perform transverse pushover analysis for Bent 3. The results from such analysis are summarized as below:

<u>Tension Column</u>

$$L_p = 62.39\, in$$
$$\Delta_p = 27.99\, in$$
$$\Delta_c = 11.48 + 27.99 = 39.47\, in$$
$$\mu_c = \frac{39.47}{11.48} = 3.4$$

<u>Compression Column</u>

$$L_p = 62.39\, in$$
$$\Delta_p = 22.77\, in$$
$$\Delta_c = 9.71 + 22.77 = 32.48\, in$$
$$\mu_c = \frac{32.48}{9.71} = 3.3$$

<u>Estimating the Seismic Demand</u>

$$k_e^3 = \frac{F_y}{\Delta_y} = \frac{0.193 \times 3{,}278}{11.48} = 55.11\, \frac{k}{in}$$

and the period of vibration, T, is calculated to be

$$T = 2\pi \times \sqrt{\frac{8.56}{55.11}} = 2.5\, \sec$$

From ARS curve, the spectral acceleration $a_3$ is read to be 0.29 g. The maximum seismic displacement demand is estimated as

$$\Delta_d = \frac{8.56 \times (0.29 \times 32.2 \times 12)}{55.11} = 17.41\,in$$

Therefore,

$$\mu_d = \frac{17.41}{11.48} = 1.5 < 5$$

and also $\Delta_d = 17.41\,in < \Delta_c = 32.48\,in.$

## II.C.2.ii $P - \Delta$ Check

We have relatively heavily loaded tall columns. $P - \Delta$ effects could be significant for this type of situation. Instead of requiring that such effects be calculated, the Seismic Design Criteria recommends that such effects can be ignored if these are limited to 20% of column capacity i.e.

$$P_{dl} \times \Delta_D \leq 0.20 \times M_p^{col}$$ SDC Eqn. (4.3)

where

$P_{dl}$ = Dead load axial force.

$\Delta_D$ = The lateral offset between the base of the plastic hinge and the point of contra-flexure.

<u>For Bent 2 Columns</u>

Column Axial Dead Load = 1,694 kips.
Plastic Moment Capacity = 13,838 ft-kips.
Maximum Seismic Displacement = 16.73 in.

$$\frac{P_{dl} \times \Delta_r}{M_p} = \frac{1{,}694 \times 16.73}{(13{,}838 \times 12)} = 0.17 < 0.20$$ OK

<u>For Bent 3 Columns</u>

Column Axial Dead Load = 1,653 kips.
Plastic Moment Capacity = 13,777 ft-kips.
Maximum Seismic Displacement = 17.51 in.

$$\frac{P_{dl} \times \Delta_r}{M_p} = \frac{1{,}653 \times 17.51}{(13{,}777 \times 12)} = 0.18 < 0.20$$ OK

Now we can see that although the selected column section has more than enough ductility capacity, the column sections meet the $P-\Delta$ requirements only by a small margin.

### II.C.2.iii Minimum Lateral Strength Capacity (0.1g)

According to the SDC (Section 3.5), the minimum lateral strength of each column shall be 0.1g. From the force deflection data shown in Appendix M, the minimum lateral strength of Bent 2 is 0.19g or 0.095g for each column (close to 0.1g ok).

## II.C.3. Column Shear and Bent Cap Capacity Check

### II.C.3.i Column Shear Check

According to the SDC, the seismic demand shall be based upon the overstrength shear, $V_0$, associated with the column overstrength moment $M_0$ (SDC Sec 4.3.1). Since shear failure tends to be brittle, shear capacity for ductile members shall be conservatively determined using nominal material properties.

According to SDC

$$\phi \times V_n \geq V_0 \qquad \phi = 0.85 \qquad \text{SDC Eqn. (3.14)}$$

where nominal shear capacity, $V_n$, is given as summation of concrete and steel shear capacities i.e.

$$V_n = V_c + V_s \qquad \text{SDC Eqn. (3.15)}$$

- Shear Demand $V_0$

For Bent 2, $M_0 = 1.2 \times M_p = 1.2 \times 14{,}964 = 17{,}957 \ ft-kips$

This overstrength moment includes the effects of overturning.

Shear demand associated with overstrength moment,

$$V_0 = \frac{M_0}{L} = \frac{17{,}957}{44} = 408 \ kips$$

Alternately, the maximum shear demand can also be determined from *wFRAME* results. The maximum column shear demand reported by such analysis is multiplied by a factor of 1.2 to obtain the shear demand associated with the overstrength moment. From *wFRAME* output, the maximum column shear demand equals $1.2 \times 349 = 419$ *kips.* See *wFRAME* output results in Appendix L.

The presence of soil around the footing results in a slightly shorter effective column length which in turn causes slightly higher column shear demand in *wFRAME* output.

- Concrete Shear Capacity

$V_c = \nu_c \times A_e$ SDC Eqn. (3.16)

where

$\nu_c =$ Allowable concrete shear stress

$A_e = 0.8 \times A_g$ SDC Eqn. (3.17)

Now

$\upsilon_c = f_1 \times f_2 \times \sqrt{f_c^{'}} \leq 4\sqrt{f_c^{'}}$ SDC Eqn. (3.18)

As one can see from the equations for concrete shear capacity, the plastic hinge region is more critical as the capacity will be lower in the this region. Further, the shear capacity will be smallest when the axial load is low. The controlling shear capacity will be found in the tension column. Now

$$f_1 = 0.3 \leq \frac{\rho_s \times f_{yh}}{0.150} + 3.67 - \mu_d < 3$$ SDC Equation (3.20)

where for circular column, the confinement reinforcement ratio is given as

$$\rho_s = \frac{4 \times A_b}{D^{'} \times s}$$

For our case,

$A_b = 0.79\ in^2$

$D' = 72 - 2 - 2 - \frac{1.13}{2} - \frac{1.13}{2} = 66.87\ in$

$s = 5\ in$

Making these substitutions in above equation yields

$\rho_s = 0.009451$

From the pushover analysis results, the displacement ductility, $\mu_d = 1.6$.

Using $f_{yh} = 60\ ksi$ and $\mu_d = 1.6$, the shear capacity factor $f_1$ is calculated to be 5.85.

However, as limited by above equation, use $f_1 = 3$.

Similarly

$$f_2 = 1 + \frac{P_c}{2{,}000 \times A_g} = 1 + \frac{907 \times 10^3}{2{,}000 \times \frac{\pi}{4} \times (6 \times 12)^2} = 1.11 < 1.5 \qquad \text{SDC Equation (3.21)}$$

The maximum allowable concrete shear stress is calculated as

$$\upsilon_c = 3 \times 1.11 \times \sqrt{4{,}000} = 211\ psi < 4\sqrt{4{,}000} = 253\ psi$$

Use $\upsilon_c = 211\ psi$.

$$\therefore V_c = \frac{211 \times 0.8 \times \frac{\pi}{4} \times (6 \times 12)^2}{1{,}000} = 687\ kips$$

- Transverse Reinforcement Shear Capacity

$$V_s = \left( \frac{A_v \times f_{yh} \times D'}{s} \right) \text{ where } A_v = n \times \frac{\pi}{2} A_b$$

where n=number of individual interlocking spiral or hoop core sections.

As specified in the SDC Sec. 3.6.5.2, the minimum shear reinforcement in column should not be less than

$$A_{v,\min} = \geq 0.025 \times \frac{D' s}{f_{yh}} = 0.14\ in^2$$

$A_{v,provided} = 0.79\ in^2$ (The area of #8 hoop rebar). OK

$$\therefore V_s = \frac{\pi}{2} \times \frac{0.79 \times 60 \times 66.87}{5} = 996\ kips$$

But according to SDC Sec. (3.6.5.1), the maximum shear strength, $V_s$, provided by steel shall not exceed $8 \times \sqrt{f_c'} \times A_e = 1{,}648$ kips. Therefore,

$$\phi \times V_n = 0.85 \times (687 + 996) = 1{,}431\ kips > V_0 = 419\ kips. \qquad \text{OK.}$$

Similarly for Bent 3 columns, the shear demand corresponding the overstrength moment is estimated as

$$V_0 = \frac{M_0}{L} = \frac{1.2 \times 14{,}893}{47} = 380\ kips$$

From the *wFRAME* analysis results, the maximum column shear demand = $1.2 \times 341 = 409\ kips$.

Going through similar calculations, we determine that

$\phi \times V_n = 0.85 \times (681 + 996) = 1{,}425\ kips > V_0 = 409\ kips.$

Although no calculations are done here, the column shear key shall be designed for axial and shear forces associated with column overstrength moment including the effects on overturning. As recommended in SDC Sec. (7.6.7), the key reinforcement shall be located as close to the center of the column as possible in order to minimize developing a force couple within the shear key reinforcement. Steel pipes may be used to relieve congestion and reduce the moment generated within the key.

## II.C.3.ii Bent Cap Flexural and Shear Capacity

According to SDC (Section 3.4), a bent cap is considered a capacity protected member and shall be designed flexurally to remain essentially elastic when the column reaches its overstrength capacity. The expected nominal moment capacity $M_{ne}$ for capacity protected members can be determined either by a traditional strength method or by a more complete $M - \phi$ analysis. The expected nominal moment capacity shall be based upon the expected concrete and steel strength values when either concrete strain reaches 0.003 or the steel strain reaches $\varepsilon_{SU}^{R}$ as derived from the applicable stress-strain relationship. Appendix G shows *xSECTION* model of the bent cap. As mentioned earlier, effective bent cap width is calculated as per SDC Sec. 7.3.1.1. The design for service loading had resulted in the following main reinforcement for the bent cap:

| | |
|---|---|
| Top Reinforcement | 22 - #11 rebars |
| Bottom Reinforcement | 24 - #11 rebars |

Ignoring the side face reinforcement, the flexural capacity of bent cap is estimated to be

$$M^{+ve} = 21{,}189\ ft - kips \qquad M^{-ve} = 19{,}436\ ft - kips$$

The Appendices H1 and H2 show such values. The seismic flexural and shear demands in the bent cap are calculated corresponding to the column overstrength moment. These demands are obtained from a new *wFRAME* push over analysis of Bent 2 with column moment capacity to be $M_0$. As shown in Appendix N (right side push over), bent cap moment demands are:

$$M^{+ve} = 14{,}350 \ ft - kips \qquad M^{-ve} = 15{,}072 \ ft - kips$$

Next the maximum seismic shear demand that corresponds to the column overstrength moment is compared with the available shear capacity of the bent cap. The maximum demand, $V_0$, as read from the above pushover analysis is $2{,}009\,kips.$ The shear capacity of bent cap at the face is calculated as below:

$$\phi \times V_n \geq V_0 \qquad\qquad \phi = 0.85$$

$$V_n = V_c + V_s$$

The shear capacity of bent cap is calculated as per Bridge Design Specifications (BDS) Sec. 8.16.6.2.

Conservatively, $V_c = 2 \times \sqrt{f_c^{'}} b_w d$ (lbs,in) BDS Eqn. (8-49)

Using

$f_c^{'} = 4000 \ psi.$

$b_w = 96.00 \ in.$

$d = 81 - 4.2 - \dfrac{1.63}{2} = 75.99 \ in.$

$V_c = 923 \ kips.$

Now

$$V_s = \frac{A_v \times f_{yh} \times d}{s}$$ BDS Eqn. (8-53)

As shown in Figure 16, the shear reinforcement in this region of maximum shear consists of 6-legged, #6 stirrups @ 8 in c/c giving total shear capacity of

$$\therefore V_s = (6 \ legs) \times \frac{0.44 \times 60 \times 75.99}{8} = 1{,}505 \ kips$$

$\phi \times V_n = 0.85 \times (923 + 1{,}505) = 2{,}064 \ kips > V_0 = 2{,}009 \ kips.$ OK.

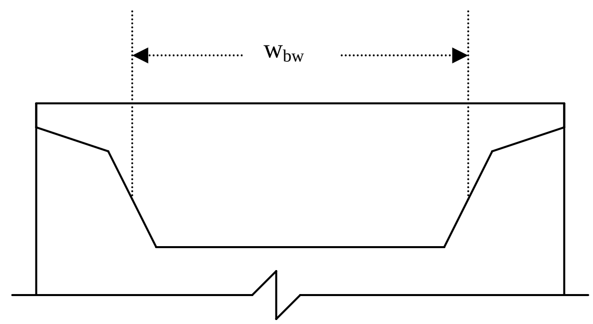
# II.D. Longitudinal Pushover Analysis and Design

## II.D.1 Abutment Soil Springs

This prototype bridge is supported on seat type abutments. It is Caltrans design practice to design the abutment backwall so that it breaks off in shear during the seismic event. The linear-elastic abutment model is based upon the effective stiffness that accounts for expansion gap and incorporates realistic values for the embankment fill response. The abutment embankment fill stiffness is non-linear and is highly dependent upon the properties of the backfill. SDC Section 7.8 describes the procedure of modeling longitudinal stiffness of abutments.

For our case of seat type abutment, the effective area, $A_e$ is given as

$$A_e = h_{bw} \times w_{bw}$$




where
$h_{bw} =$ Back wall height
$w_{bw} =$ Superstructure width.

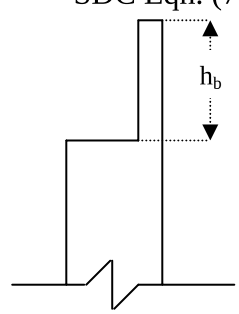
For our case,
$A_e = 6.75 \times 46.46 = 313.6\ ft^2$

As per SDC Figure 7.14C, the effective abutment width is taken as average normal width of the superstructure.

The maximum passive pressure, $P_w$, resisting the abutment is given as

$$P_w = A_e \times 5\ ksf \times \left(\frac{h_{bw}}{5.5}\right) kips \qquad \text{SDC Eqn. (7.44)}$$

$$= 313.6 \times 5 \times \left(\frac{6.75}{5.5}\right) = 1{,}924\ kips$$



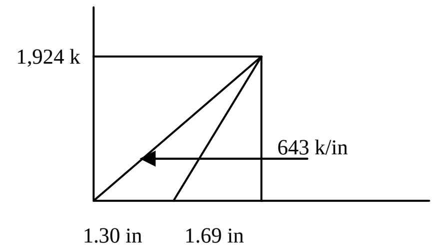

The initial embankment stiffness now can be calculated as

Based upon initial embankment fill stiffness, $K_i \approx 20\left(\frac{kips/in}{ft}\right)$, initial abutment stiffness is adjusted proportional to the backwall height as

$$K_{abut} = K_i \times w \times \left(\frac{h}{5.5}\right)$$

$$K_{abut} = 20 \times 46.46 \times \left(\frac{6.75}{5.5}\right) = 1{,}140\ \frac{k}{in}$$

$$\Delta = \frac{F}{K} = \frac{1{,}924}{1{,}140} = 1.69\ in$$




$\Delta_{effective} = \Delta + \Delta_{gap} = 1.69 + 1.30 = 2.99\ in.$ See Appendix O for calculations for $\Delta_{gap}$, the combined effect of thermal movement and anticipated shortening. Average contributory length is used for this purpose.

$$K_{initial}^{Abut} = \frac{1{,}924}{2.99} = 643\ kips/in$$

This value is used as the starting abutment stiffness for the longitudinal push over analysis. The Appendix P lists *wFRAME* input file. When the structure has reached its plastic limit state, we calculate the longitudinal bridge stiffness as

$k_{long} = \dfrac{0.38 \times 8{,}430}{9.13} = 351\ kips/in.$ See Appendix Q1.

Mass, $m = \dfrac{W}{g} = \dfrac{8{,}430}{32.2 \times 12} = 21.82\ kips - s^2/in$

$$T = 2 \times \pi \times \sqrt{\frac{m}{k_{long}}} = 2 \times \pi \times \sqrt{\frac{21.82}{351}} = 1.57\ \text{sec}$$

$$S_a = 0.48g$$

$$\Delta_D = \frac{F}{K} = \frac{m \times a}{K} = \frac{21.82 \times 0.48 \times 32.2 \times 12}{351} = 11.53\ in$$

$$R_A = \frac{\Delta_D}{\Delta_{effective}} = \frac{11.53}{2.99} = 3.86$$

According to SDC Sec. 7.8.1,

$$K_{final}^{Abut} = K_{initial}^{Abut} \times \left[1.0 - \left(\frac{R_A - 2}{4 - 2}\right) \times 0.9\right]$$

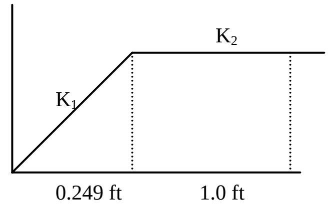
$$= 643 \times \left[1.0 - \left(\frac{3.86 - 2}{4 - 2}\right) \times 0.9\right] = 643 \times (0.163) = 105\ kips/in.$$

The following stiffness values shall be used for all subsequent *wFRAME* longitudinal analyses:

$K_1 = 1{,}260\ kips/\ ft$ and $\Delta_1 = 0.249\ ft$

and

$K_2 = 0$ and $\Delta_2 = 1.0\ ft$

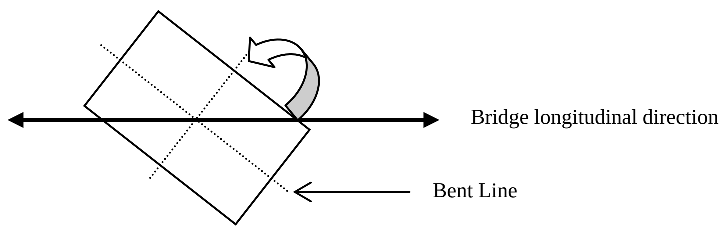


## II.D.2 Ductility Analysis

### II.D.2.i Ductility Capacity and Ductility Demand Check

Although the process of calculating the section capacity and the estimated seismic demand is similar to that for the transverse direction, there are some significant differences:

- Columns are lumped together.
- Because superstructure is prestressed, gross moment of inertia is used for the superstructure.
- Bent overturning is ignored.
- The abutment is modeled as a linear spring whose stiffness is calculated as described in the previous section.
- The calculations for determining section capacity for the longitudinal bending are similar because the columns have circular cros-section. If the section were rectangular, section properties along the longitudinal direction of the bridge must be calculated and used. This can be achieved by specifying, in *xSECTION* input file, the angle between the column section coordinate system and the longitudinal direction of the bridge as shown below.




Both left and right push over analyses are performed. The yield displacements of Bent 2 and Bent 3 are determined to be

| Location | Yield Disp. (Right Push) | Yield Disp. (Left Push) |
|---|---|---|
| Bent 2 | 8.86 in | 8.35 in |
| Bent 3 | 9.10 in | 9.82 in |

The plastic deformation capacities for both Bent 2 and Bent 3 are exactly the same as calculated for the transverse bending for the case of gravity loading. This is because the longitudinal case has very little overturning to change the column axial loads.

$\Delta_p = 22.15\, in$ for Bent 2
and
$\Delta_p = 24.93\, in$ for Bent 3

Now
With $\Delta_c = \Delta_Y + \Delta_P$

For Bent 2
$$Min \quad \mu_c = \frac{\Delta_c}{\Delta_Y} = \left(\frac{8.86 + 22.15}{8.86}\right) = 3.5 > 3$$ SDC Sec. 3.1.4 OK.

Similarly, for Bent 3 Column,
$$Min \quad \mu_c = \frac{\Delta_c}{\Delta_Y} = \left(\frac{9.82 + 24.93}{9.82}\right) = 3.5 > 3$$ SDC Sec. 3.1.4 OK.

Appendix Q2 lists force-displacement relationship from *wFRAME* analysis. The bridge (frame) longitudinal stiffness is calculated from this plot when both columns have yielded. This stage represents the collapse mechanism.

$$k_{long} = \frac{0.187 \times 8{,}430}{9.10} = 173 \; kips / in.$$
$T = 2.2 \sec$ for which $S_a = 0.31g$
$\Delta_D = 15.11 \; in.$ This demand is the same at Bents 2 and 3 because the superstructure constrains the bents to move together. This might not be the case when the bridge has significant foundation flexibility, which can result from rotational and/or translational foundation movements.

Check Displacement Ductility

$$Max \; \mu_D = \frac{15.11}{8.35} = 1.8 \text{ for Bent 2 } < 5$$ OK
$$Max \; \mu_D = \frac{15.11}{9.10} = 1.6 \text{ for Bent 3} < 5$$ OK

## II.D.2.ii Check $P - \Delta$ (SDC Sec 4.2)

For Bent 2 Columns

$$\frac{P_{dl} \times \Delta_r}{M_p} = \frac{1{,}694 \times 15.11}{(13{,}838 \times 12)} = 0.15 < 0.20$$ OK

For Bent 3 Columns

$$\frac{P_{dl} \times \Delta_r}{M_p} = \frac{1{,}653 \times 15.11}{(13{,}777 \times 12)} = 0.15 < 0.20$$ OK

## II.D.2.iii Minimum Lateral Strength

The minimum lateral strength, as read from Appendix Q2, is 0.19g. It meets the requirement of SDC section 3.5.

## II.D.3 Column Shear Check

As per SDC, the maximum shear demand corresponds to $V_0$. Note that *wFRAME* output numbers represent total shear for both columns at each bent. The column shear capacity is calculated following the procedures outlined in the transverse bending case on pages 21-23.

Bent 2

$V_0 = 1.2 \times V_P = 388\ kips.$ It corresponds to max shear value of $V_P$=323 kips/column obtained from the *wFRAME* push over analysis.
For $\mu_D = 1.8$, factor1=5.65 > 3. Use factor1=3
For dead load axial force, factor2=1.21
$v_c = 230\ psi$ which gives $V_c = 749\ kips$
$V_s = 996\ kips.$ Calculated earlier.
$\phi \times (V_c + V_s) = 1{,}483\ kips > V_0 = 388\ kips$ OK

Bent 3

$V_0 = 1.2 \times V_P = 378\ kips.$ It corresponds to max shear value of 315 kips/column obtained from the *wFRAME* push over
For $\mu_D = 1.7$, factor1=5.85 > 3. Use factor1=3
For dead load axial force, factor2=1.20
$v_c = 228\ psi$ which gives $V_c = 743\ kips$
$V_s = 996\ kips.$ which has been calculated earlier.
$\phi \times (V_c + V_s) = 1{,}478\ kips > V_0 = 378\ kips$ OK

## II.D.4 Seismic Strength of Concrete Bridge Superstructures

We often seem to forget that when moment-resisting superstructure-to-column details are used, seismic forces of significant magnitude are induced into the superstructure. If the superstructure does not have adequate capacity to resist such forces, unexpected and unintentional hinge formation can occur in the superstructure leading to potential failure of the superstructure. According to the Seismic Design Criteria, a capacity design approach is adopted to ensure that the superstructure must have an appropriate strength reserve above demands generated from probable column plastic hinging. Memo to Designers (MTD) 20-6 describes the philosophy, design criteria and a procedure for determining the seismic demands in the superstructure and also recommends a method for determining the flexural capacity of the superstructure at all critical locations.

### II.D.4.i General Assumptions

As discussed in MTD 20-6, the following are some of the assumptions that are made for simplifying the process of calculating the seismic demands in the superstructure:

- The superstructure demands are based upon complete plastic hinge formation in all columns or piers within the frame.

- Effective section properties shall be used for modeling columns or piers while gross section properties may be used for superstructure elements.

- Superstructure dead load and secondary prestress demands are assumed to be uniformly distributed to each girder, except in case of highly curved or highly skewed structures.

- While assessing the superstructure member demands and available section capacities, an effective width as defined in the SDC Section 7.2.1.1 will be used.

### II.D.4.ii Determining Seismic Demand in the Superstructure

The force demand in the superstructure corresponds to its Collapse Limit State. The Collapse Limit State is defined as the condition when all the potential plastic hinges in columns and/or piers have been formed. When a bridge reaches such a state during a seismic event, the following loads are present:

- Dead Loads
- Secondary Prestress Loads
- Seismic Loads

It should be noted that since the prestress tendon is treated as an internal component of the superstructure and is included in the member strength calculation, only the secondary effects which are caused by the support constraints in a statically indeterminate prestressed frame, are considered to contribute to the member demand.

The procedure to determine extreme seismic demands in the superstructure considers each of these load cases separately and the final member demand is obtained by the superposition of the individual load cases. Since we shall be using different tools to calculate these demands, it is *very important* to use a consistent sign convention while interpreting results. We shall adopt the following sign convention for positive moments and positive shears. The *CTBridge* program uses a similar sign convention. It should be kept in mind that the *wFRAME* program uses a sign convention that is different to this adopted sign convention.

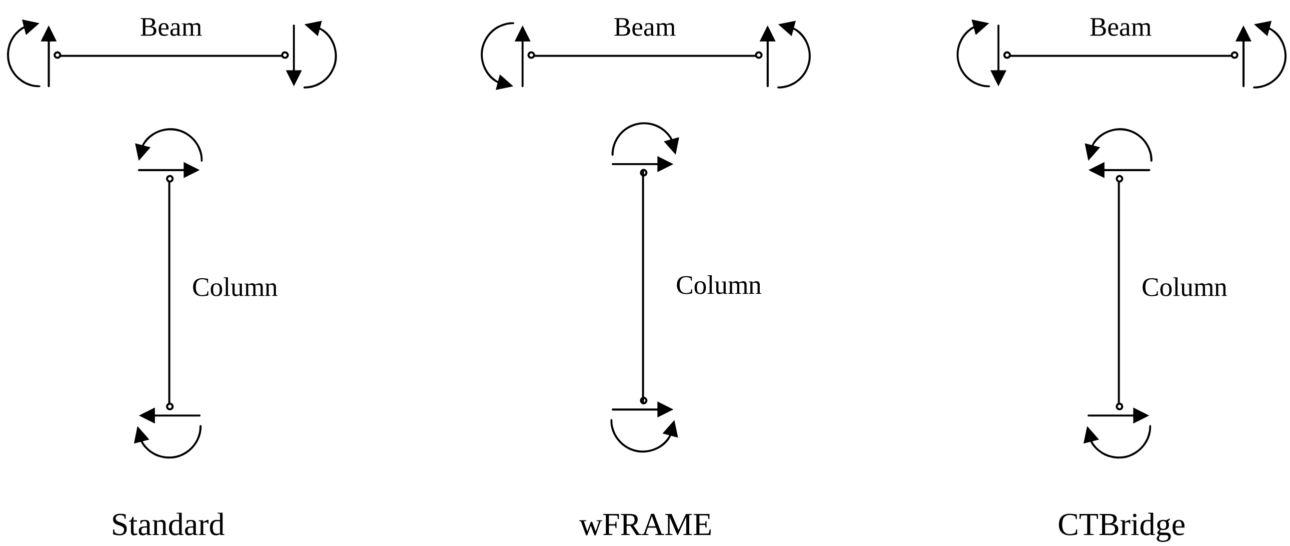



**Figure 4 Sign Convention for Positive Moment and Positive Shear for Various Programs**

Prior to the application of seismic loading, the columns are "pre-loaded" with moments and shears due to dead loads and secondary prestress effects. At the Collapse Limit State, the "earthquake moment" applied to the superstructure may be greater or less than the overstrength moment capacity of the column or pier depending upon the direction of these "pre-load" moments and the direction of the seismic loading under consideration. The load and secondary prestress effects to reach its overstrength moment capacity of the columns. Figure 5 shows schematically this approach of calculating columns seismic forces.

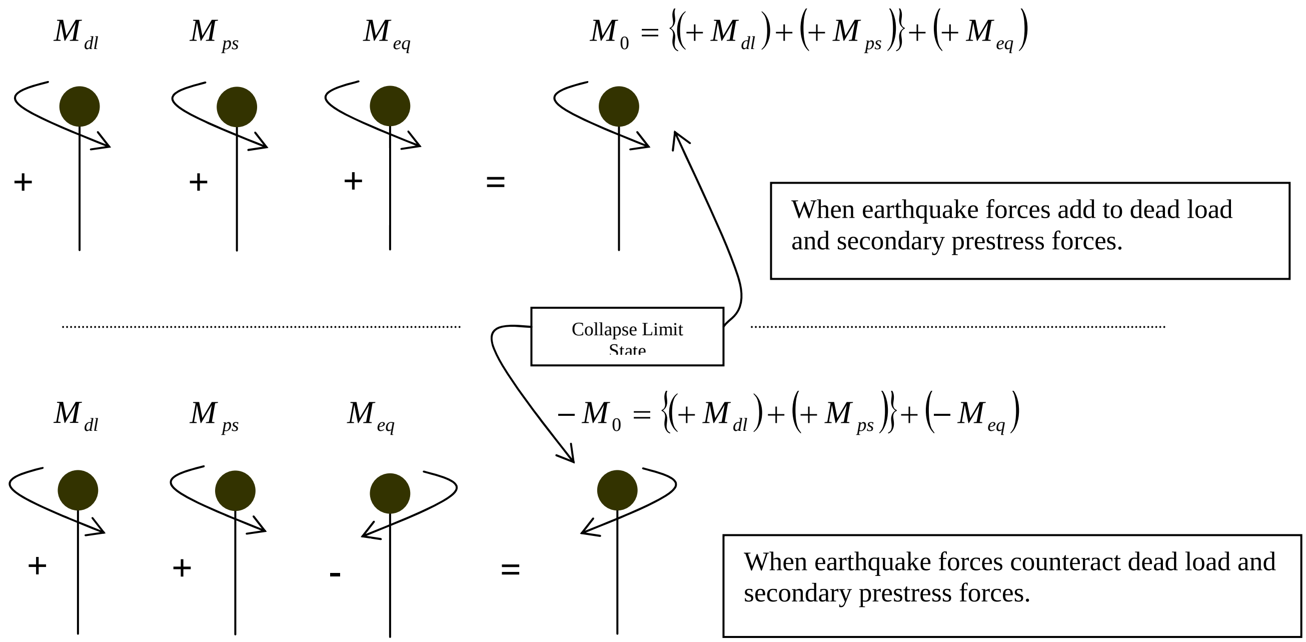
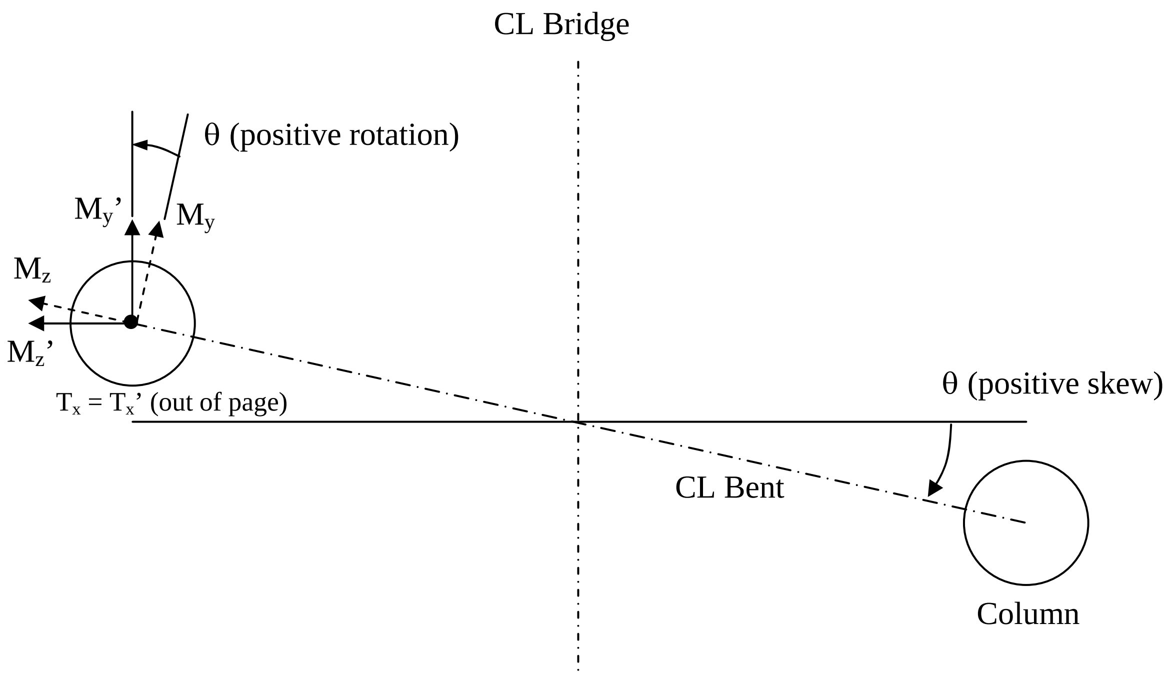



**Figure 5 Column Forces Corresponding to Two Seismic Loading Cases**

Once the column moment, $M_{eq}$, is known at each potential plastic hinge location below the joint regions, the seismic moment demand in the superstructure can be determined using currently available Caltrans analysis tools by either of the following approaches. In the first method, these moments are applied at the column-superstructure joints and the *SAP2000* program can be used to compute the moment demand in the superstructure members. The second method involves using the *wFRAME* program to perform a longitudinal push over analysis by specifying the required seismic moments in the columns as the plastic hinge capacities of the column ends which are moment-connected to the superstructure. The push over is continued until all the plastic hinges have been formed. In our case, we shall use this method to compute the distribution of seismic moments in the superstructure members.

Note that *CTBridge* is a three-dimensional analysis program where force results are oriented in the direction of each member's local axis. Since we will be using *wFRAME*, a two-dimensional frame analysis program, to determine the distribution of seismic forces to the superstructure, we need to make sure the dead load and secondary prestress moments lie in the same plane prior to using them in any calculations. This must be done especially when horizontal curves or skews are involved. Consequently for this prototype bridge, the top of bent support results from *CTBridge* will need to be transformed to a consistent planar coordinate system (i.e. the plane formed by the centerline of bridge and the vertical axis). To do so, the following coordinate transformation will be applied to the top of column moments from *CTBridge*:




$M_z' = M_z \cos\theta - M_y \sin\theta$ (Longitudinal Moment)
$M_y' = M_z \sin\theta + M_y \cos\theta$ (Transverse Moment)
$T_x' = T_x$ (Torsional Moment)

| | | | DL | | | ADL | | | Sec. PS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bent** | **Location** | **Skew** | $M_z$ | $M_y$ | $M_{long}$ | $M_z$ | $M_y$ | $M_{long}$ | $M_z$ | $M_y$ | $M_{long}$ |
| **2** | **Soffit** | 20 | -1189 | 91 | -1148 | -213 | 17 | -206 | 82 | -371 | 204 |
| **3** | **Soffit** | 20 | 1305 | -1 | 1227 | 234 | -1 | 220 | -127 | 287 | -218 |

It should be kept in mind that the above values are for both columns in each bent.

As recommended in MTD 20-6, due to the uncertainty of the magnitude and distribution of secondary prestress moments and shears at the extreme seismic limit state, it is conservative to consider such effects only when their inclusion results in increased demands in the superstructure.

Now these methodologies are applied to our bridge to calculate the extreme seismic forces in the superstructure corresponding to the Collapse Limit State of the bridge.

## II.D.4.iii Determine Dead Load and Additional Dead Load Moments

These dead load moments are readily available from the *CTBridge* output. Table 1.1 lists these moments at every 1/10$^{th}$ point of the span length and at the face of supports. These moments are assumed to be uniformly distributed along each girder.

<u>At Bent 2</u>

Column moment at base, $M_{dl}^{col,bottom} = 0\ ft-kip$ (*CTBridge* Output)
Column moment at deck soffit, $M_{dl}^{col,top@joint} = \{(-1{,}148)+(-207)\} = -1{,}355\ ft-kip$

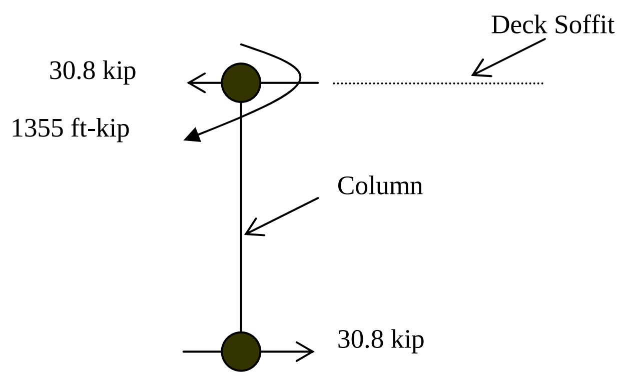



**Figure 6 Free Body Diagram Showing Equilibrium of Dead Loading at Bent 2**

At Bent 3

Column moment at base, $M_{dl}^{col,top@joint} = 0\ ft - kip$ (*CTBridge* Output)

Column moment at deck soffit, $M_{dl}^{col,top@joint} = \{(+1{,}227) + (+220)\} = +1{,}447\ ft - kip$

## II.D.4.iv Determine Prestress Secondary Moments

Once again, the secondary prestress moments are obtained directly from the *CTBridge* output. These moments are assumed to be uniformly distributed along each girder. Table 1.1 lists these moments at every 1/10$^{th}$ point of the span length and at the face of supports.

At Bent 2

Column moment at base, $M_{ps}^{col,bottom} = 0\ ft - kip$ (*CTBridge* Output)

Column moment at deck soffit, $M_{ps}^{col,top@joint} = +204\ ft - kip$

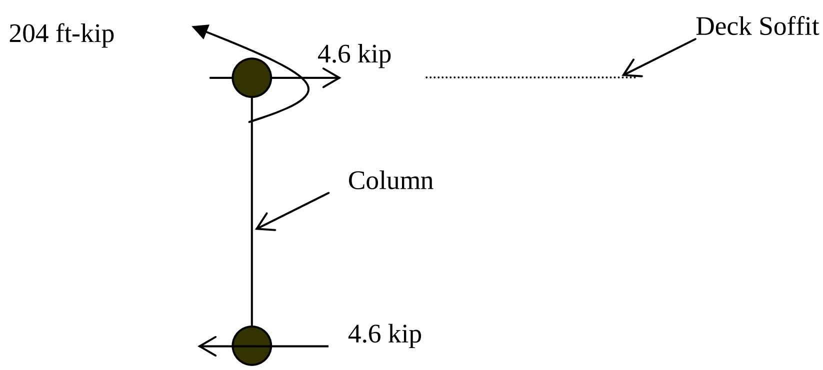



**Figure 7 Free Body Diagram Showing Equilibrium of Secondary Prestress Forces at Bent 2**

At Bent 3

Column moment at base, $M_{ps}^{col,bottom} = 0\ ft-kip$ (*CTBridge* Output)

Column Moment at deck soffit, $M_{ps}^{col,top@joint} = -218\ ft-kip$

### II.D.4.v Determine Earthquake Moments

### II.4.D.v.a Determine the amount of seismic loading needed to ensure that potential plastic hinges have formed in all the columns of the framing system

To form a plastic hinge in the column, the seismic load needs to produce a moment at the potential plastic hinge location of such a magnitude that, when combined with the "pre-loaded" dead load and prestress moments, the column will reach an overstrength plastic moment capacity, $M_0^{col}$.

$$M_0^{col@soffit} = M_{dl}^{col@soffit} + M_{ps}^{col@soffit} + M_{eq}^{col@soffit}$$

It should be kept in mind that dead load moments will have positive or negative values depending upon the location along the span length. Also, the direction of seismic loading will determine the nature of the seismic moments.

The column seismic load moments, $M_{eq}^{col}$, are calculated from this equation based upon the principle of superposition as follows:

$$M_{eq}^{col@soffit} = M_0^{col@soffit} - \left(M_{dl}^{col@soffit} + M_{ps}^{col@soffit}\right)$$

In these equations, the overstrength column moment as given as

$$M_o^{col} = 1.2 \times M_p^{col} \qquad \text{SDC Equation (4.4)}$$

Two cases of longitudinal earthquake loading are considered.

Case 1) The Bridge Moves from Abutment 1 towards Abutment 4

As shown in Figure 8, such loading results in positive moments in the columns according to the sign convention used here.

Bent 2

As calculated above, the columns have already been “pre-loaded” by:

$$M_{dl}^{col\,@\,soffit} + M_{ps}^{col\,@\,soffit} = \{(-1{,}355) + (+204)\} = -1{,}151\,ft - kip.$$

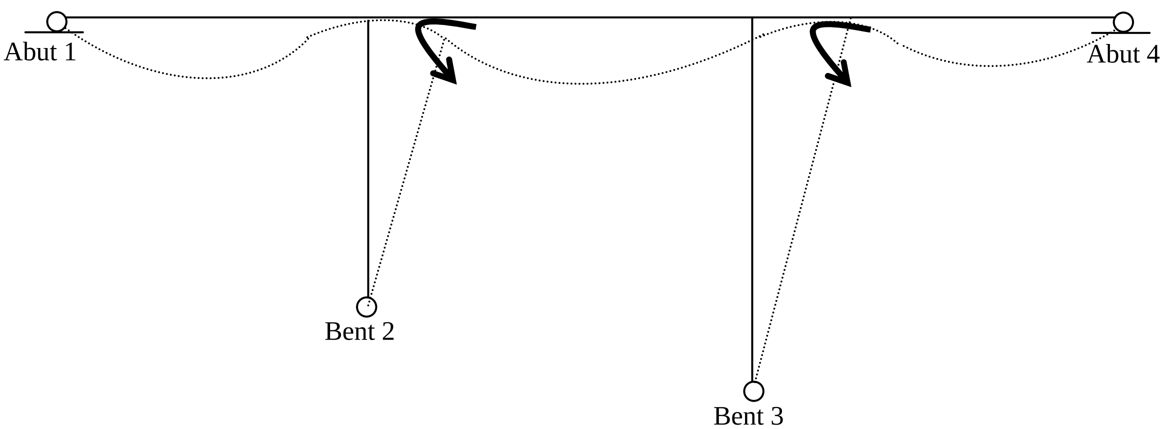



**Figure 8 Seismic Loading Case “1” Producing Positive Moments in Columns**

Now, the amount of column moment that will be generated by the seismic loading so that the column reaches its overstrength moment capacity will be

$$\begin{aligned} M_{eq}^{col\,@\,soffit} &= 1.2 \times M_{p}^{col\,@\,soffit} - (M_{dl}^{col} + M_{ps}^{col\,@\,soffit}) \\ &= 1.2 \times (2\ Columns) \times 13{,}838 - \{(-1{,}355) + 0\} = +34{,}566\ ft - kip \end{aligned}$$

It should be noted that the secondary prestress moment is *neglected* because doing so results in increased seismic demand on the column and hence in the superstructure. As recommended in MTD20-6 and discussed earlier, this practice is considered conservative because of the uncertainty associated with the magnitude and distribution of prestress secondary moments.

Figure 9 schematically explains this superposition approach.

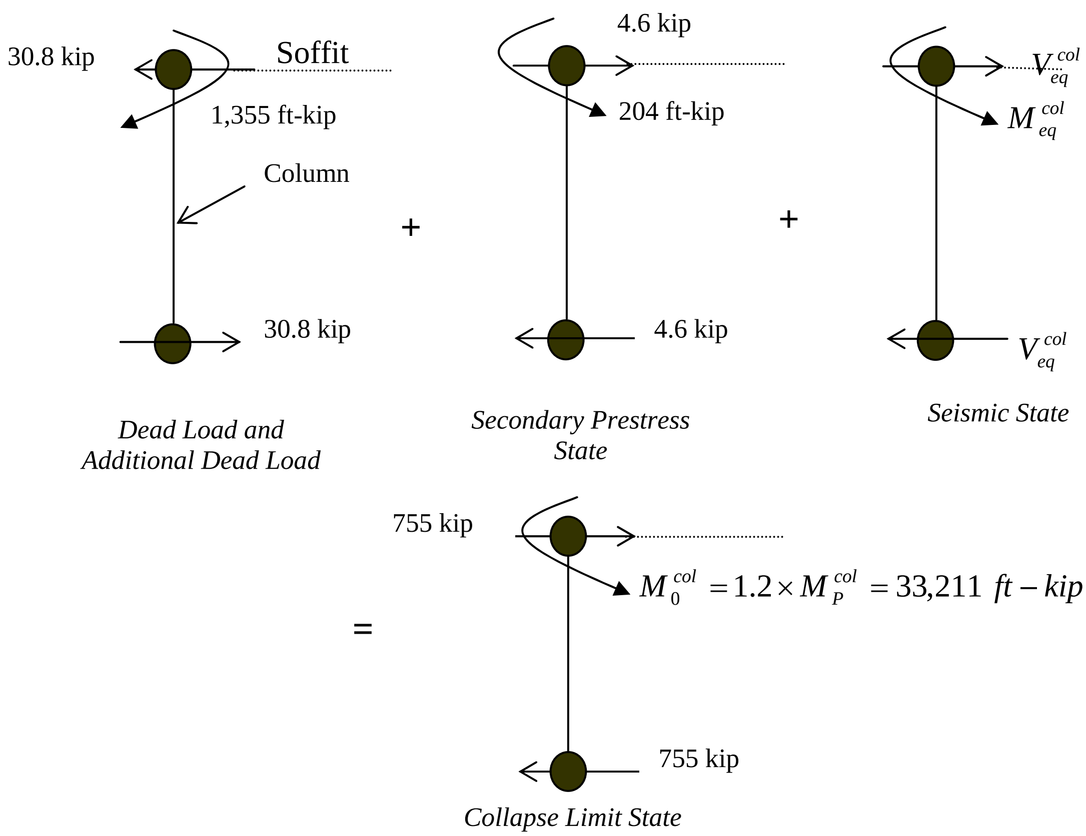



**Figure 9 Superposition of Column Forces at Bent 2 for Loading Case "1"**

Bent 3

Following a similar approach, the amount of column moment that will be generated by the seismic loading so that the column reaches its overstrength moment capacity will be

$$M_{eq}^{col\,@\,soffit} = 1.2 \times (2\ Columns) \times 13{,}777 - (1{,}447 - 218) = 31{,}835\ ft-kip$$

It should be noted that in this case, the effect of secondary prestress moments is *included* because doing so results in increased seismic moment in the columns and hence in the superstructure.

Case 2) The Bridge Moves from Abutment 4 toward Abutment 1

As shown in Figure 10, such loading results in negative moments in the columns according to our sign convention.

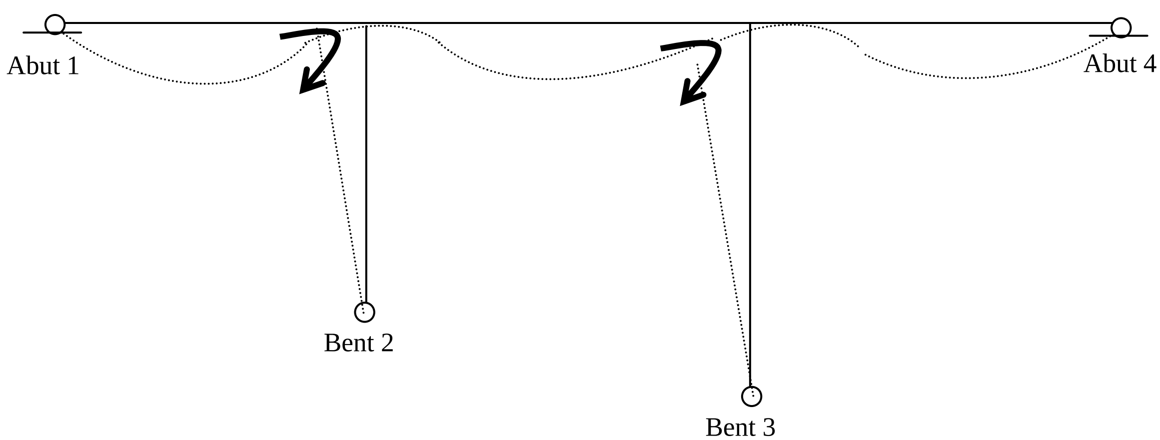



**Figure 10 Seismic Loading Case "2" Producing Negative Moments in Columns**

Following the same procedure as outlined earlier, the maximum column seismic moments at bents 2 and 3 are calculated to be

$$M_{eq}^{col@soffit} = 1.2 \times M_p^{col} - (M_{dl}^{col} + M_{ps}^{col}) = 1.2 \times (2\ Columns) \times (-13{,}838) - (-1{,}355 + 204) = -32{,}060\ ft - kip$$

$$M_{eq}^{col@soffit} = 1.2 \times M_p^{col} - (M_{dl}^{col} + M_{ps}^{col}) = 1.2 \times (2\ Columns) \times (-13{,}777) - (1{,}447 - 0) = -34{,}512\ ft - kip$$

respectively.

Please note the negative sign associated with the column overstrength moment capacity., indicating that the seismic loading being considered here produces negative column moments according to our sign convention.

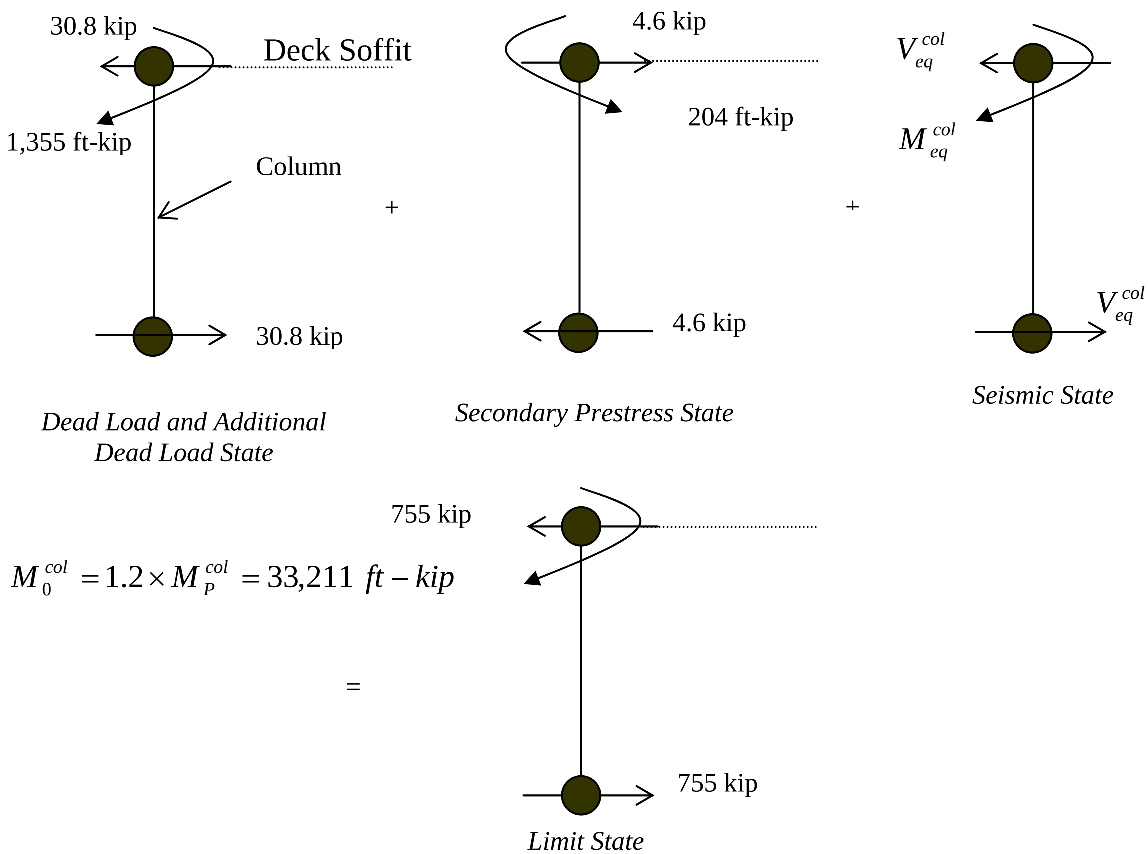



**Figure 11 Superposition of Column Forces at Bent 2 for Loading Case "2"**

Figure 11 schematically shows the Free Body Diagram at Bent 2 for this seismic loading case.

Now that we know the extreme seismic moments in columns, let us find distribution of these moments in the superstructure

## II.4.v.b Determine the earthquake moment in the superstructure

The static non-linear "push-over" frame analysis program *wFRAME* will now be used to distribute the column earthquake moments and shears into the superstructure.
The sign convention for positive moment and shear forces used in *wFRAME* is opposite to the one being used here. Appendix R shows the input file to the *wFRAME* program. Note that the superstructure dead load has been removed from the *wFRAME* model. As can be seen from this input file the positive column earthquake moments corresponding to "Case 1" loading are used as negative column moment capacities for "push-over" analysis while the negative column earthquake moments corresponding to "Case 2" are modeled as positive column moment capacities.

Table 1.2 lists the distribution of earthquake moments in the superstructure as obtained from these "push-over" analyses. See Appendix S for Case 1 results in Table 1.2.

## II.D.4.vi Compute Moment and Shear Demand at Location of Interest

The extreme seismic moment demand in the superstructure is now calculated as the summation of all the moments calculated in steps 3.1 through 3.3, taking into account the proper direction of bending in each case as well as the effective section width. The superstructure demand moments are defined as

$$M_D^L = M_{dl}^L + M_{ps}^L + M_{eq}^L$$

and

$$M_D^R = M_{dl}^R + M_{ps}^R + M_{eq}^R$$

at the left and right sides of the column, respectively. Dead load and prestress moment demands in the superstructure are proportioned based upon the number of girders falling within the effective section width. The earthquake moment imparted by column is also assumed to act within the same effective section width.

Let us calculate superstructure moment demand at the face of the cap on each side of the column.

<u>Bent 2: At the left face of Bent Cap</u>

The effective section width, $b_e = D_c + 2 \times D_s = 6.00 + 2 \times 6.75 = 19.50\,ft$

Based upon the column location and the girder spacing, it can easily be concluded that the girder aligned along the centerline of the bridge lies outside the effective width.

Therefore, at the face of bent cap, four girders are within the effective section.

The per girder values used below have been listed in Table 1.1.

Case 1)

$$M_{dl}^{L} = \{(-6{,}520) + (-1{,}164)\} \times (4\,girders) = -30{,}736\,ft - kip.$$

$$M_{ps}^{L} = \{+1{,}734\} \times (4\,girders) = +6{,}936\,ft - kip$$

Now the $M_{eq}^{L} = -15{,}015\,ft - kip$. This value is listed in Table 1.2

The superstructure moment demand is then calculated as

$$M_{D}^{L} = (-30{,}736) + (6{,}936^{*}) + (-15{,}015) = -45{,}751\,ft - kip$$

Similarly,

$$M_{D}^{R} = (-31{,}730) + (6{,}744) + (21{,}135) = -3{,}821\,ft - kip$$

Table 1.3 lists these superstructure seismic moment demands.

Case 2)

$$M_{eq}^{L} = +13{,}201\,ft - kip$$

The superstructure moment demand in this case becomes

$$M_{D}^{L} = (-30{,}736) + (6{,}936) + (13{,}201) = -10{,}599\,ft - kip$$

The superstructure demand on the right side of the column is calculated to be

$$M_{D}^{R} = (-31{,}730) + (6{,}774^{*}) + (-20{,}295) = -52{,}025\,ft - kip$$

[*] The prestressing secondary effect is ignored as doing so results in a conservatively higher seismic demand in the superstructure.

The superstructure moment demands around Bent 3 are calculated to be:

$$M_{D}^{L} = \begin{cases} -49{,}702\,ft - kip & \text{Case 1} \\ -3{,}002\,ft - kip & \text{Case 2} \end{cases}$$

and

$$M_D^R = \begin{cases} -9{,}431\,ft-kip & \text{Case 1} \\ -43{,}914\,ft-kip & \text{Case 2} \end{cases}$$

The seismic moment demands along the superstructure length have been summarized in the form of moment envelope values tabulated in Table 1.3

Now a similar procedure can be followed to calculate the seismic shear force demand in the superstructure.

Once again the shear forces in the superstructure member due to dead load, additional dead load, and secondary prestress are readily available from the *CTBridge* output. Table 1.4 lists these values.

The superstructure seismic shear forces due to seismic moments can be obtained directly from the *wFRAME* output or calculated by using the previously computed values of the superstructure seismic moments, $M_{eq}^L$ *and* $M_{eq}^R$ , for each span. In our case, the values of $V_{eq}$ for Span 1 are calculated to be:

<u>Case 1)</u>

Seismic Moment at Abutment 1, $M_{eq}^{(1)} = 0\,ft-kip$

Seismic Moment at Bent 2, $M_{eq}^{(2)} = -15{,}381\,ft-kip$

Shear force in Span , $V_{eq} = \dfrac{\left(M_{eq}^{(2)} - M_{eq}^{(1)}\right)}{\text{Length of Span 1}} = \dfrac{(-15{,}381-0)}{126} = -122kip$

<u>Case 2)</u>

Seismic Moment at Abutment 1, $M_{eq}^{(1)} = 0\,ft-kip$

Seismic Moment at Bent 2, $M_{eq}^{(2)} = 13{,}523\,ft-kip$

Shear force in Span , $V_{eq} = \dfrac{\left(M_{eq}^{(2)} - M_{eq}^{(1)}\right)}{\text{Length of Span 1}} = \dfrac{(13{,}523-0)}{126} = 107kip$

Similarly, the seismic shear forces for the remaining spans are calculated to be:

Span 2, $V_{eq} = \begin{cases} -253kip & \text{Case 1} \\ +253kip & \text{Case 2} \end{cases}$

Span 3, $V_{eq} = \begin{cases} -115kip & \text{Case 1} \\ +133kip & \text{Case 2} \end{cases}$

Table 1.5 lists these values. Once again, the extreme seismic shear force demand in the superstructure is now calculated as the summation of shear forces due to dead load, secondary prestress effects and the seismic loading, taking into account the proper direction of bending in each case and the effective section width. The superstructure demand shear forces are defined as $V_D^L = V_{dl}^L + V_{ps}^L + V_{eq}^L$ and $V_D^R = V_{dl}^R + V_{ps}^R + V_{eq}^R$ at the left and right side of the column, respectively. Once again, the effect due to the secondary prestress will be considered only when doing so results in increased seismic demand.

Table 1.6 lists the maximum shear demand summarized as a shear envelope.

## II.D.4.vii Superstructure Section Capacity

Now that we have calculated the extreme moment and shear seismic demands, let us calculate the corresponding section capacity to make sure that the superstructure has sufficient capacity to resist the demands.

### II.D.4.vii.a Superstructure Flexure Capacity

MTD 20-6 describes the philosophy behind the flexural section capacity calculations. The member strength and curvature capacities are assessed using a stress-stain compatibility analysis. Failure is reached when either the ultimate concrete, mild steel or prestressing ultimate strain is reached. Figure 12 shows such equilibrium:

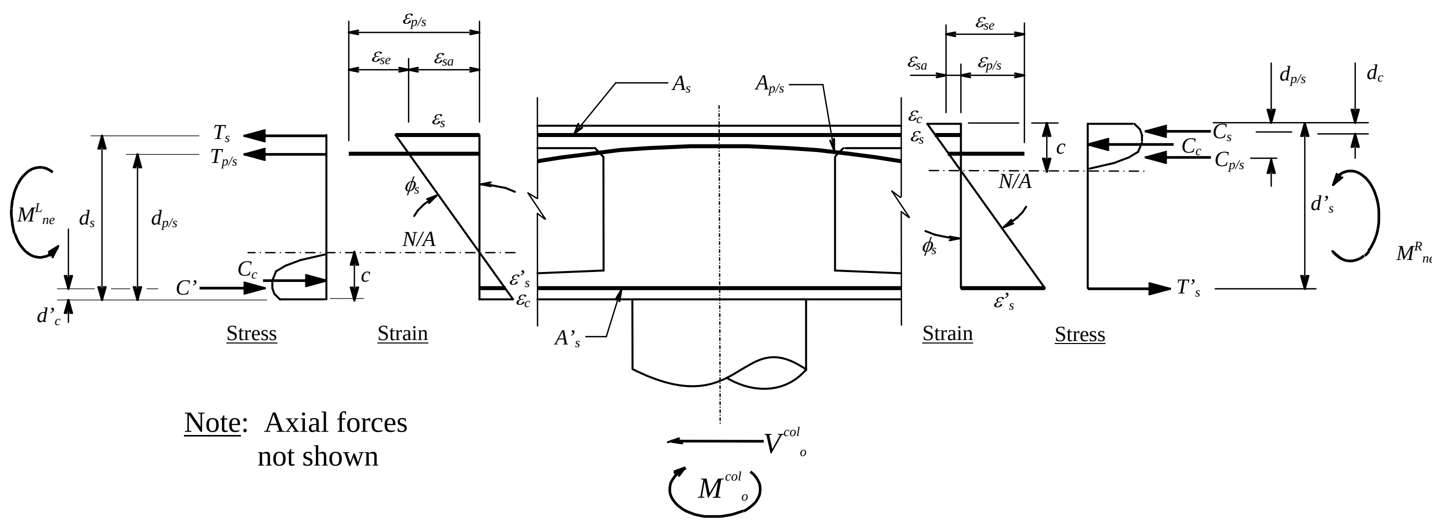



**Figure 12 Superstructure Capacity Provided by Internal Couple**

As stated in MTD20-6, the empirical relationships in AASHTO LRFD Section 5.7.3 do not accurately reflect prestress member strength or address the issue of bonded tendon ductility, and therefore, are not used in this example. The computer program PSSECx is used to calculate the section flexural capacity. The program has the option to use either a "simple" model or "Mander's unconfined" model to represent the unconfined concrete stress-strain relationship. The material properties used for 270ksi prestressing strands are given in SDC Section 3.2.4. According to MTD20-6, at locations where additional longitudinal mild steel is not required by analysis, as a minimum, an equivalent of #8 @12 (maximum spacing not to exceed 12") should be placed in the top and bottom slabs at the bent cap. Such reinforcement will extend beyond the inflection points for the seismic moment demand envelope. For A706 reinforcing steel , the material properties are given in SDC Section 3.2.3. As specified in SDC Section 3.4, the expected nominal moment capacity, $M_{ne}$ for capacity protected concrete components shall be determined by either $M-\phi$ or strength design. Also, expected material properties are to be used. Expected nominal moment capacity for these capacity-protected concrete members shall be based upon the expected concrete and steel strengths when either the concrete strain reaches its ultimate value based upon the stress-strain model or the reduced ultimate prestress steel strain, $\varepsilon_{su}^{R}$ =0.03, as specified in SDC 3.2.4. Besides these material properties, the following additional information also needs to be supplied:

<u>Prestressing Steel</u>

- Eccentricity of Prestressing Steel - Obtained from the *CTBridge* output file. This value is referenced from the CG of the section.
- Prestressing Force - Obtained from the *CTBridge* output file under the "P/S Response After Long Term Losses" tables.
- Prestressing Steel Area, $A_{ps}$ Calculated for 270ksi steel as

$$A_{ps} = \frac{P_{jack}}{(0.75)\times 270}$$

<u>Mild Steel</u>

- Amount of Top Slab Steel Known as per design including #8 @12 that is put in a priori.
- Location of Top Slab Steel Referenced from CG of section. Known from section depth, assumed cover, etc.
- Amount of Bottom Slab Steel Known as per design including #8 @12 that is put in a priori.
- Location of Bottom Slab Steel Referenced from CG of section. Known from section depth, assumed cover, etc.

Table 1.7 lists these data that will be used to calculate the flexural section capacity.

The computer program *PSSECx* was run repeatedly to calculate superstructure flexural capacities at various points along the span length. Both negative (tension at the top) and positive (tension at the bottom) capacities were calculated at various sections along the length of the bridge. Table 1.8 lists these capacities and also compares them with the maximum moment demands. As can be seen from these results, the superstructure has sufficient flexural capacity to meet the anticipated seismic demands. It is suggested that $\phi_{flexure} = 1.0$ be used as we are dealing with extreme conditions corresponding to column overstrength.

Appendix T lists the *PSSECx* input for the superstructure section that lies just left of Bent 2. The model is shown in Appendix U. The results for negative capacity calculations are shown in Appendix W. As stated earlier, the flexural capacity is determined when either the steel or concrete strain reaches its respective maximum value. In this case, the maximum allowable value of steel strain is reached before concrete reaches its maximum. The worst ratio D/C ratio of 0.63 suggests overdesign. If such case is found across a broad spectrum of various Caltrans bridges, perhaps the requirement of #8 @12 may be revised in the future.

### II.D.4.vii.b Superstructure Shear Capacity

According to MTD 20-6, the superstructure shear capacity is calculated as per AASHTO LRFD. As shear failure is a brittle, nominal rather than expected material properties are used to calculate the shear capacity of the superstructure using $\phi_{shear} = 0.90$. Table 1.9 compares the seismic shear demands with the available section shear capacity.

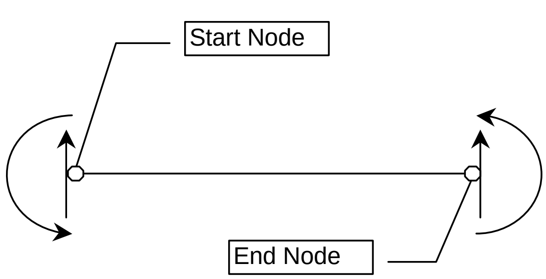
Table 1.1 Dead Load and Secondary Prestress Momnets

## Moments (k-ft) from CTBridge Output

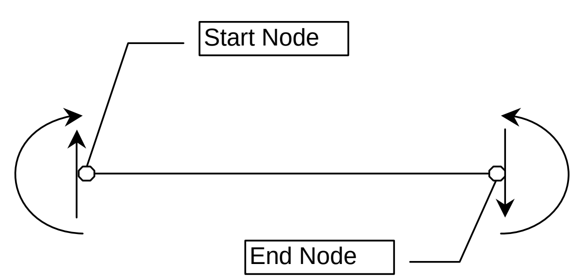
| | Location | | Whole Superstructure Width | | | Per Girder | | |
|---|---|---|---|---|---|---|---|---|
| | | | $M_{DL}$ | $M_{ADL}$ | $M_{PS}$ | $M_{DL}$ | $M_{ADL}$ | $M_{PS}$ |
| Span 1 | **Support** | 1.5 | 619 | 114 | 647 | 124 | 23 | 129 |
| | **0.1** | 12.6 | 7110 | 1275 | 1462 | 1422 | 255 | 292 |
| | **0.2** | 25.2 | 12158 | 2178 | 2272 | 2432 | 436 | 454 |
| | **0.3** | 37.8 | 14741 | 2640 | 3096 | 2948 | 528 | 619 |
| | **0.4** | 50.4 | 14857 | 2661 | 3956 | 2971 | 532 | 791 |
| | **0.5** | 63 | 12508 | 2240 | 4705 | 2502 | 448 | 941 |
| | **0.6** | 75.6 | 7693 | 1377 | 5617 | 1539 | 275 | 1123 |
| | **0.7** | 88.2 | 412 | 74 | 6400 | 82 | 15 | 1280 |
| | **0.8** | 100.8 | -9334 | -1671 | 7911 | -1867 | -334 | 1582 |
| | **0.9** | 113.4 | -21553 | -3857 | 8498 | -4311 | -771 | 1700 |
| | **Support** | 123 | -32599 | -5819 | 8672 | -6520 | -1164 | 1734 |
| Span 2 | **Support** | 129 | -33654 | -6009 | 8468 | -6731 | -1202 | 1694 |
| | **0.1** | 142.8 | -17502 | -3136 | 9516 | -3500 | -627 | 1903 |
| | **0.2** | 159.6 | -1955 | -354 | 9005 | -391 | -71 | 1801 |
| | **0.3** | 176.4 | 9208 | 1645 | 8318 | 1842 | 329 | 1664 |
| | **0.4** | 193.2 | 15989 | 2859 | 8281 | 3198 | 572 | 1656 |
| | **0.5** | 210 | 18388 | 3289 | 8027 | 3678 | 658 | 1605 |
| | **0.6** | 226.8 | 16406 | 2935 | 8072 | 3281 | 587 | 1614 |
| | **0.7** | 243.6 | 10043 | 1795 | 7905 | 2009 | 359 | 1581 |
| | **0.8** | 260.4 | -699 | -128 | 8355 | -140 | -26 | 1671 |
| | **0.9** | 277.2 | -15820 | -2835 | 8645 | -3164 | -567 | 1729 |
| | **Support** | 291 | -31614 | -5646 | 7554 | -6323 | -1129 | 1511 |
| Span 3 | **Support** | 297 | -30429 | -5434 | 7482 | -6086 | -1087 | 1496 |
| | **0.1** | 305.8 | -20789 | -3723 | 7275 | -4158 | -745 | 1455 |
| | **0.2** | 317.6 | -9854 | -1766 | 6861 | -1971 | -353 | 1372 |
| | **0.3** | 329.4 | -1093 | -197 | 5559 | -219 | -39 | 1112 |
| | **0.4** | 341.2 | 5506 | 986 | 4870 | 1101 | 197 | 974 |
| | **0.5** | 353 | 9943 | 1781 | 4085 | 1989 | 356 | 817 |
| | **0.6** | 364.8 | 12219 | 2189 | 3417 | 2444 | 438 | 683 |
| | **0.7** | 376.6 | 12333 | 2210 | 2669 | 2467 | 442 | 534 |
| | **0.8** | 388.4 | 10286 | 1844 | 1945 | 2057 | 369 | 389 |
| | **0.9** | 400.2 | 6077 | 1091 | 1230 | 1215 | 218 | 246 |
| | **Support** | 410.5 | 637 | 117 | 529 | 127 | 23 | 106 |

Table 1.2 Earthquake Moments

| Earthquake Moments (k-ft) from wFRAME Output | | | | | |
|---|---|---|---|---|---|
| Location | | $M_{EQ}$ | | | |
| | | **wFRAME Convention** | | **Standard Convention** | |
| | | **Case 1** | **Case 2** | **Case 1** | **Case 2** |
| **Span 1** | **0.0** | 0 | 0 | 0 | 0 |
| | **Support** | | | -183 | 161 |
| | **0.1** | | | -1538 | 1352 |
| | **0.2** | | | -3076 | 2705 |
| | **0.3** | | | -4614 | 4057 |
| | **0.4** | | | -6152 | 5409 |
| | **0.5** | | | -7691 | 6761 |
| | **0.6** | | | -9229 | 8114 |
| | **0.7** | | | -10767 | 9466 |
| | **0.8** | | | -12305 | 10818 |
| | **0.9** | | | -13843 | 12170 |
| | **Support** | | | -15015 | 13201 |
| | **1.0** | -15381 | 13523 | -15381 | 13523 |
| **Span 2** | **0.0** | -21895 | 21055 | 21895 | -21055 |
| | **Support** | | | 21135 | -20295 |
| | **0.1** | | | 17640 | -16798 |
| | **0.2** | | | 13385 | -12540 |
| | **0.3** | | | 9131 | -8282 |
| | **0.4** | | | 4876 | -4024 |
| | **0.5** | | | 621 | 234 |
| | **0.6** | | | -3634 | 4492 |
| | **0.7** | | | -7889 | 8750 |
| | **0.8** | | | -12144 | 13008 |
| | **0.9** | | | -16399 | 17266 |
| | **Support** | | | -19894 | 20763 |
| | **1.0** | -20653 | 21524 | -20653 | 21524 |
| **Span 3** | **0.0** | -13620 | 15621 | 13620 | -15621 |
| | **Support** | | | 13274 | -15223 |
| | **0.1** | | | 12258 | -14059 |
| | **0.2** | | | 10896 | -12496 |
| | **0.3** | | | 9534 | -10934 |
| | **0.4** | | | 8172 | -9372 |
| | **0.5** | | | 6810 | -7810 |
| | **0.6** | | | 5448 | -6248 |
| | **0.7** | | | 4086 | -4686 |
| | **0.8** | | | 2724 | -3124 |
| | **0.9** | | | 1362 | -1562 |
| | **Support** | | | 173 | -199 |
| | **1.0** | 0 | 0 | 0 | 0 |




wFRAME Positive Convention




Standard Positive Convention

Table 1.3 Moment Demand Envelope

## Moment Demand (k-ft) Envelope

| | Location | | No. of Girders in Effective Section | $M_{DL}$ | $M_{ADL}$ | $M_{PS}$ | Case 1 $M_{EQ}$ | Case 2 $M_{EQ}$ | Case 1 $M_{positive}$ | Case 1 $M_{negative}$ | Case 2 $M_{positive}$ | Case 2 $M_{negative}$ | Envelope $M_{positive}$ | Envelope $M_{negative}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Span 1** | **Support** | 1.5 | 4 | 496 | 91 | 517 | -183 | 161 | 921 | 403 | 1265 | 748 | 1265 | 403 |
| | **0.1** | 12.6 | 5 | 7110 | 1275 | 1462 | -1538 | 1352 | 8309 | 6847 | 11199 | 9737 | 11199 | 6847 |
| | **0.2** | 25.2 | 5 | 12158 | 2178 | 2272 | -3076 | 2705 | 13532 | 11260 | 19313 | 17041 | 19313 | 11260 |
| | **0.3** | 37.8 | 5 | 14741 | 2640 | 3096 | -4614 | 4057 | 15862 | 12766 | 24533 | 21438 | 24533 | 12766 |
| | **0.4** | 50.4 | 5 | 14857 | 2661 | 3956 | -6152 | 5409 | 15321 | 11365 | 26883 | 22927 | 26883 | 11365 |
| | **0.5** | 63.0 | 5 | 12508 | 2240 | 4705 | -7691 | 6761 | 11762 | 7057 | 26213 | 21509 | 26213 | 7057 |
| | **0.6** | 75.6 | 5 | 7693 | 1377 | 5617 | -9229 | 8114 | 5459 | -159 | 22801 | 17184 | 22801 | -159 |
| | **0.7** | 88.2 | 5 | 412 | 74 | 6400 | -10767 | 9466 | -3881 | -10281 | 16352 | 9952 | 16352 | -10281 |
| | **0.8** | 100.8 | 5 | -9334 | -1671 | 7911 | -12305 | 10818 | -15399 | -23310 | 7724 | -187 | 7724 | -23310 |
| | **0.9** | 113.4 | 5 | -21553 | -3857 | 8498 | -13843 | 12170 | -30755 | -39254 | -4742 | -13240 | -4742 | -39254 |
| | **Support** | 123.0 | 4 | -26079 | -4656 | 6937 | -15015 | 13201 | -38812 | -45750 | -10597 | -17534 | -10597 | -45750 |
| **Span 2** | **Support** | 129.0 | 4 | -26923 | -4807 | 6774 | 21135 | -20295 | -3820 | -10595 | -45251 | -52025 | -3820 | -52025 |
| | **0.1** | 142.8 | 5 | -17502 | -3136 | 9516 | 17640 | -16798 | 6518 | -2998 | -27920 | -37436 | 6518 | -37436 |
| | **0.2** | 159.6 | 5 | -1955 | -354 | 9005 | 13385 | -12540 | 20082 | 11077 | -5843 | -14848 | 20082 | -14848 |
| | **0.3** | 176.4 | 5 | 9208 | 1645 | 8318 | 9131 | -8282 | 28301 | 19984 | 10889 | 2571 | 28301 | 2571 |
| | **0.4** | 193.2 | 5 | 15989 | 2859 | 8281 | 4876 | -4024 | 32005 | 23724 | 23105 | 14824 | 32005 | 14824 |
| | **0.5** | 210.0 | 5 | 18388 | 3289 | 8027 | 621 | 234 | 30324 | 22297 | 29938 | 21911 | 30324 | 21911 |
| | **0.6** | 226.8 | 5 | 16406 | 2935 | 8072 | -3634 | 4492 | 23779 | 15707 | 31905 | 23833 | 31905 | 15707 |
| | **0.7** | 243.6 | 5 | 10043 | 1795 | 7905 | -7889 | 8750 | 11854 | 3950 | 28493 | 20588 | 28493 | 3950 |
| | **0.8** | 260.4 | 5 | -699 | -128 | 8355 | -12144 | 13008 | -4616 | -12970 | 20536 | 12181 | 20536 | -12970 |
| | **0.9** | 277.2 | 5 | -15820 | -2835 | 8645 | -16399 | 17266 | -26409 | -35054 | 7256 | -1390 | 7256 | -35054 |
| | **Support** | 291.0 | 4 | -25291 | -4517 | 6043 | -19894 | 20763 | -43659 | -49702 | -3002 | -9045 | -3002 | -49702 |
| **Span 3** | **Support** | 297.0 | 4 | -24344 | -4347 | 5986 | 13274 | -15223 | -9431 | -15417 | -37928 | -43914 | -9431 | -43914 |
| | **0.1** | 305.8 | 5 | -20789 | -3723 | 7275 | 12258 | -14059 | -4979 | -12254 | -31296 | -38571 | -4979 | -38571 |
| | **0.2** | 317.6 | 5 | -9854 | -1766 | 6861 | 10896 | -12496 | 6138 | -724 | -17255 | -24116 | 6138 | -24116 |
| | **0.3** | 329.4 | 5 | -1093 | -197 | 5559 | 9534 | -10934 | 13804 | 8244 | -6665 | -12224 | 13804 | -12224 |
| | **0.4** | 341.2 | 5 | 5506 | 986 | 4870 | 8172 | -9372 | 19533 | 14663 | 1988 | -2881 | 19533 | -2881 |
| | **0.5** | 353.0 | 5 | 9943 | 1781 | 4085 | 6810 | -7810 | 22619 | 18534 | 7999 | 3913 | 22619 | 3913 |
| | **0.6** | 364.8 | 5 | 12219 | 2189 | 3417 | 5448 | -6248 | 23273 | 19856 | 11576 | 8159 | 23273 | 8159 |
| | **0.7** | 376.6 | 5 | 12333 | 2210 | 2669 | 4086 | -4686 | 21298 | 18629 | 12526 | 9857 | 21298 | 9857 |
| | **0.8** | 388.4 | 5 | 10286 | 1844 | 1945 | 2724 | -3124 | 16799 | 14854 | 10950 | 9006 | 16799 | 9006 |
| | **0.9** | 400.2 | 5 | 6077 | 1091 | 1230 | 1362 | -1562 | 9760 | 8530 | 6836 | 5606 | 9760 | 5606 |
| | **Support** | 410.5 | 4 | 509 | 94 | 423 | 173 | -199 | 1199 | 776 | 827 | 404 | 1199 | 404 |

**$M_{negative} = M_{EQ, min} + M_{DL} + M_{ADL} + M_{PS}$****

**$M_{positive} = M_{EQ, max} + M_{DL} + M_{ADL} + M_{PS}$***

**$M_{negative} = M_{EQ, min} + M_{DL} + M_{ADL} + M_{PS}$****

*** Only include $M_{PS}$ when it maximizes $M_{positive}$**

**** Only include $M_{PS}$ when it minimizes $M_{negative}$**

Table 1.4 Dead Load and Secondary Prestress Shear Forces

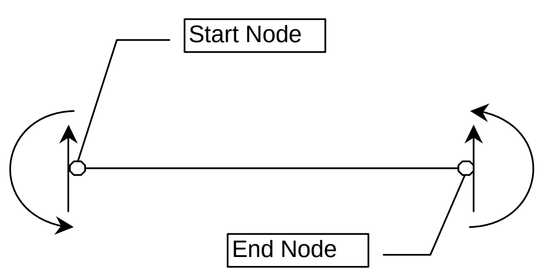
## Shear (k) from CTBridge Output

| | Location | | Whole Superstructure Width | | | Per Girder | | |
|---|---|---|---|---|---|---|---|---|
| | | | $V_{DL}$ | $V_{ADL}$ | $V_{PS}$ | $V_{DL}$ | $V_{ADL}$ | $V_{PS}$ |
| **Span 1** | **Support** | 1.5 | 671 | 120 | 79 | 134 | 24 | 16 |
| | **0.1** | 12.6 | 498 | 89 | 78 | 100 | 18 | 16 |
| | **0.2** | 25.2 | 303 | 54 | 76 | 61 | 11 | 15 |
| | **0.3** | 37.8 | 107 | 19 | 76 | 21 | 4 | 15 |
| | **0.4** | 50.4 | -89 | -16 | 75 | -18 | -3 | 15 |
| | **0.5** | 63.0 | -284 | -51 | 75 | -57 | -10 | 15 |
| | **0.6** | 75.6 | -480 | -86 | 75 | -96 | -17 | 15 |
| | **0.7** | 88.2 | -675 | -121 | 75 | -135 | -24 | 15 |
| | **0.8** | 100.8 | -871 | -156 | 75 | -174 | -31 | 15 |
| | **0.9** | 113.4 | -1070 | -191 | 30 | -214 | -38 | 6 |
| | **Support** | 123.0 | -1232 | -218 | 134 | -246 | -44 | 27 |
| **Span 2** | **Support** | 129.0 | 1287 | 227 | -44 | 257 | 45 | -9 |
| | **0.1** | 142.8 | 1056 | 189 | -22 | 211 | 38 | -4 |
| | **0.2** | 159.6 | 795 | 142 | 2 | 159 | 28 | 0 |
| | **0.3** | 176.4 | 534 | 96 | 2 | 107 | 19 | 0 |
| | **0.4** | 193.2 | 273 | 49 | 2 | 55 | 10 | 0 |
| | **0.5** | 210.0 | 13 | 2 | 2 | 3 | 0 | 0 |
| | **0.6** | 226.8 | -248 | -45 | 1 | -50 | -9 | 0 |
| | **0.7** | 243.6 | -509 | -91 | 1 | -102 | -18 | 0 |
| | **0.8** | 260.4 | -770 | -138 | 1 | -154 | -28 | 0 |
| | **0.9** | 277.2 | -1031 | -185 | -28 | -206 | -37 | -6 |
| | **Support** | 291.0 | -1261 | -223 | 37 | -252 | -45 | 7 |
| **Span 3** | **Support** | 297.0 | 1171 | 207 | -118 | 234 | 41 | -24 |
| | **0.1** | 305.8 | 1021 | 182 | -69 | 204 | 36 | -14 |
| | **0.2** | 317.6 | 834 | 149 | -48 | 167 | 30 | -10 |
| | **0.3** | 329.4 | 651 | 117 | -48 | 130 | 23 | -10 |
| | **0.4** | 341.2 | 468 | 84 | -48 | 94 | 17 | -10 |
| | **0.5** | 353.0 | 284 | 51 | -49 | 57 | 10 | -10 |
| | **0.6** | 364.8 | 101 | 18 | -48 | 20 | 4 | -10 |
| | **0.7** | 376.6 | -82 | -15 | -48 | -16 | -3 | -10 |
| | **0.8** | 388.4 | -265 | -47 | -48 | -53 | -9 | -10 |
| | **0.9** | 400.2 | -448 | -80 | -48 | -90 | -16 | -10 |
| | **Support** | 410.5 | -608 | -109 | -68 | -122 | -22 | -14 |

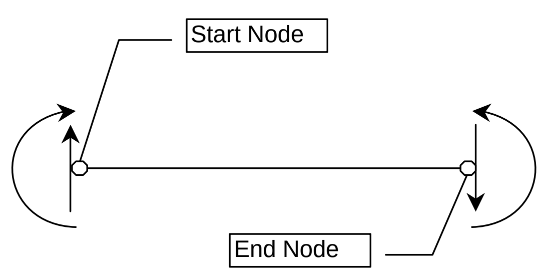
Table 1.5 Earthquake Shear Forces

## Earthquake Shear (k) from wFRAME Output

| | Location | | $V_{EQ}$ wFRAME Convention Case 1 | wFRAME Convention Case 2 | Standard Convention Case 1 | Standard Convention Case 2 |
|---|---|---|---|---|---|---|
| Span 1 | **0** | 0.0 | -122 | 107 | -122 | 107 |
| | **Support** | 1.5 | 0 | 0 | -122 | 107 |
| | **0.1** | 12.6 | 0 | 0 | -122 | 107 |
| | **0.2** | 25.2 | 0 | 0 | -122 | 107 |
| | **0.3** | 37.8 | 0 | 0 | -122 | 107 |
| | **0.4** | 50.4 | 0 | 0 | -122 | 107 |
| | **0.5** | 63.0 | 0 | 0 | -122 | 107 |
| | **0.6** | 75.6 | 0 | 0 | -122 | 107 |
| | **0.7** | 88.2 | 0 | 0 | -122 | 107 |
| | **0.8** | 100.8 | 0 | 0 | -122 | 107 |
| | **0.9** | 113.4 | 0 | 0 | -122 | 107 |
| | **Support** | 123.0 | 0 | 0 | -122 | 107 |
| | **1** | 126.0 | -122 | 107 | -122 | 107 |
| Span 2 | **0** | 126.0 | -253 | 253 | -253 | 253 |
| | **Support** | 129.0 | 0 | 0 | -253 | 253 |
| | **0.1** | 142.8 | 0 | 0 | -253 | 253 |
| | **0.2** | 159.6 | 0 | 0 | -253 | 253 |
| | **0.3** | 176.4 | 0 | 0 | -253 | 253 |
| | **0.4** | 193.2 | 0 | 0 | -253 | 253 |
| | **0.5** | 210.0 | 0 | 0 | -253 | 253 |
| | **0.6** | 226.8 | 0 | 0 | -253 | 253 |
| | **0.7** | 243.6 | 0 | 0 | -253 | 253 |
| | **0.8** | 260.4 | 0 | 0 | -253 | 253 |
| | **0.9** | 277.2 | 0 | 0 | -253 | 253 |
| | **Support** | 291.0 | 0 | 0 | -253 | 253 |
| | **1** | 294.0 | -253 | 253 | -253 | 253 |
| Span 3 | **0** | 294.0 | -115 | 133 | -115 | 133 |
| | **Support** | 297.0 | 0 | 0 | -115 | 133 |
| | **0.1** | 305.8 | 0 | 0 | -115 | 133 |
| | **0.2** | 317.6 | 0 | 0 | -115 | 133 |
| | **0.3** | 329.4 | 0 | 0 | -115 | 133 |
| | **0.4** | 341.2 | 0 | 0 | -115 | 133 |
| | **0.5** | 353.0 | 0 | 0 | -115 | 133 |
| | **0.6** | 364.8 | 0 | 0 | -115 | 133 |
| | **0.7** | 376.6 | 0 | 0 | -115 | 133 |
| | **0.8** | 388.4 | 0 | 0 | -115 | 133 |
| | **0.9** | 400.2 | 0 | 0 | -115 | 133 |
| | **Support** | 410.5 | 0 | 0 | -115 | 133 |
| | **1** | 412.0 | -115 | 133 | -115 | 133 |




wFRAME Positive Convention




Standard Positive Convention

Table 1.6 Shear Demand Envelope

## Shear Demand (k) Envelope

| | Location | | No. of Girders in Effective Section | | | | Case 1 | Case 2 | Case 1 | | Case 2 | | Envelope | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $V_{DL}$ | $V_{ADL}$ | $V_{PS}$ | $V_{EQ}$ | $V_{EQ}$ | $V_{positive}$ | $V_{negative}$ | $V_{positive}$ | $V_{negative}$ | $V_{positive}$ | $V_{negative}$ | $V_{max}$ |
| Span 1 | **Support** | 1.5 | 4 | 536 | 96 | 63 | -122 | 107 | 574 | 510 | 803 | 739 | 803 | 510 | 803 |
| | **0.1** | 12.6 | 5 | 498 | 89 | 78 | -122 | 107 | 543 | 465 | 772 | 694 | 772 | 465 | 772 |
| | **0.2** | 25.2 | 5 | 303 | 54 | 76 | -122 | 107 | 311 | 235 | 540 | 464 | 540 | 235 | 540 |
| | **0.3** | 37.8 | 5 | 107 | 19 | 76 | -122 | 107 | 80 | 4 | 309 | 233 | 309 | 4 | 309 |
| | **0.4** | 50.4 | 5 | -89 | -16 | 75 | -122 | 107 | -151 | -227 | 78 | 3 | 78 | -227 | 227 |
| | **0.5** | 63.0 | 5 | -284 | -51 | 75 | -122 | 107 | -382 | -457 | -153 | -228 | -153 | -457 | 457 |
| | **0.6** | 75.6 | 5 | -480 | -86 | 75 | -122 | 107 | -613 | -688 | -384 | -459 | -384 | -688 | 688 |
| | **0.7** | 88.2 | 5 | -675 | -121 | 75 | -122 | 107 | -843 | -918 | -614 | -689 | -614 | -918 | 918 |
| | **0.8** | 100.8 | 5 | -871 | -156 | 75 | -122 | 107 | -1075 | -1149 | -846 | -920 | -846 | -1149 | 1149 |
| | **0.9** | 113.4 | 5 | -1070 | -191 | 30 | -122 | 107 | -1354 | -1383 | -1125 | -1154 | -1125 | -1383 | 1383 |
| | **Support** | 123.0 | 4 | -986 | -174 | 107 | -122 | 107 | -1175 | -1282 | -946 | -1053 | -946 | -1282 | 1282 |
| Span 2 | **Support** | 129.0 | 4 | 1029 | 182 | -35 | -253 | 253 | 958 | 923 | 1464 | 1429 | 1464 | 923 | 1464 |
| | **0.1** | 142.8 | 5 | 1056 | 189 | -22 | -253 | 253 | 992 | 971 | 1498 | 1477 | 1498 | 971 | 1498 |
| | **0.2** | 159.6 | 5 | 795 | 142 | 2 | -253 | 253 | 686 | 684 | 1192 | 1190 | 1192 | 684 | 1192 |
| | **0.3** | 176.4 | 5 | 534 | 96 | 2 | -253 | 253 | 378 | 377 | 884 | 883 | 884 | 377 | 884 |
| | **0.4** | 193.2 | 5 | 273 | 49 | 2 | -253 | 253 | 71 | 69 | 577 | 575 | 577 | 69 | 577 |
| | **0.5** | 210.0 | 5 | 13 | 2 | 2 | -253 | 253 | -237 | -238 | 269 | 268 | 269 | -238 | 269 |
| | **0.6** | 226.8 | 5 | -248 | -45 | 1 | -253 | 253 | -544 | -546 | -38 | -40 | -38 | -546 | 546 |
| | **0.7** | 243.6 | 5 | -509 | -91 | 1 | -253 | 253 | -852 | -853 | -346 | -347 | -346 | -853 | 853 |
| | **0.8** | 260.4 | 5 | -770 | -138 | 1 | -253 | 253 | -1160 | -1161 | -654 | -655 | -654 | -1161 | 1161 |
| | **0.9** | 277.2 | 5 | -1031 | -185 | -28 | -253 | 253 | -1469 | -1496 | -963 | -990 | -963 | -1496 | 1496 |
| | **Support** | 291.0 | 4 | -1009 | -178 | 30 | -253 | 253 | -1411 | -1440 | -905 | -934 | -905 | -1440 | 1440 |
| Span 3 | **Support** | 297.0 | 4 | 937 | 165 | -94 | -115 | 133 | 987 | 893 | 1234 | 1140 | 1234 | 893 | 1234 |
| | **0.1** | 305.8 | 5 | 1021 | 182 | -69 | -115 | 133 | 1088 | 1020 | 1336 | 1267 | 1336 | 1020 | 1336 |
| | **0.2** | 317.6 | 5 | 834 | 149 | -48 | -115 | 133 | 868 | 820 | 1116 | 1068 | 1116 | 820 | 1116 |
| | **0.3** | 329.4 | 5 | 651 | 117 | -48 | -115 | 133 | 652 | 604 | 900 | 852 | 900 | 604 | 900 |
| | **0.4** | 341.2 | 5 | 468 | 84 | -48 | -115 | 133 | 436 | 388 | 684 | 636 | 684 | 388 | 684 |
| | **0.5** | 353.0 | 5 | 284 | 51 | -49 | -115 | 133 | 220 | 172 | 468 | 420 | 468 | 172 | 468 |
| | **0.6** | 364.8 | 5 | 101 | 18 | -48 | -115 | 133 | 4 | -44 | 252 | 204 | 252 | -44 | 252 |
| | **0.7** | 376.6 | 5 | -82 | -15 | -48 | -115 | 133 | -212 | -259 | 36 | -11 | 36 | -259 | 259 |
| | **0.8** | 388.4 | 5 | -265 | -47 | -48 | -115 | 133 | -428 | -476 | -180 | -228 | -180 | -476 | 476 |
| | **0.9** | 400.2 | 5 | -448 | -80 | -48 | -115 | 133 | -644 | -692 | -396 | -444 | -396 | -692 | 692 |
| | **Support** | 410.5 | 4 | -486 | -87 | -54 | -115 | 133 | -689 | -743 | -441 | -495 | -441 | -743 | 743 |

**$V_{positive} = V_{EQ, max} + V_{DL} + V_{ADL} + V_{PS}$***
**$V_{negative} = V_{EQ, max} + V_{DL} + V_{ADL} + V_{PS}$****
**$V_{max}$ = Greater of Absolute($V_{positive}$) or Absolute($V_{negative}$)**

*** Only include $V_{PS}$ when it maximizes $V_{positive}$**
**** Only include $V_{PS}$ when it minimizes $V_{negative}$**

Table 1.7 Section Flexural Capacity Calculation Data

$P_{jack}$ = 9689.9 k

| | Location | | No. Girders | No. Girders in Effective Section | Eccentricity | PS Force After All Losses | For Effective Section: PS Force After All Losses | For Effective Section: Area of PS | Area of Top Mild Steel* | Distance to Top Mild Steel | Area of Bottom Mild Steel* | Distance to Bottom Mild Steel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $e_{ps}$ in | k | k | $A_{ps}$ in$^2$ | $A_{st,top}$ in$^2$ | $y_{st,top}$ in | $A_{st,bot}$ in$^2$ | $y_{st,bot}$ in |
| Span 1 | **Support** | 1.5 | 5 | 4 | -2.6628 | 7439 | 5952 | 38.28 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.1** | 12.6 | 5 | 5 | -14.9760 | 7508 | 7508 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.2** | 25.2 | 5 | 5 | -25.1328 | 7582 | 7582 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.3** | 37.8 | 5 | 5 | -31.2264 | 7650 | 7650 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.4** | 50.4 | 5 | 5 | -33.2568 | 7712 | 7712 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.5** | 63.0 | 5 | 5 | -31.4076 | 7766 | 7766 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.6** | 75.6 | 5 | 5 | -25.8576 | 7814 | 7814 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.7** | 88.2 | 5 | 5 | -16.6068 | 7859 | 7859 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.8** | 100.8 | 5 | 5 | -3.6576 | 7839 | 7839 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.9** | 113.4 | 5 | 5 | 14.9160 | 7765 | 7765 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **Support** | 123.0 | 5 | 4 | 25.4412 | 7697 | 6157 | 38.28 | 47.40 | 31.80 | 34.76 | -42.13 |
| Span 2 | **Support** | 129.0 | 5 | 4 | 25.6116 | 7595 | 6076 | 38.28 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.1** | 142.8 | 5 | 5 | 12.0432 | 7413 | 7413 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.2** | 159.6 | 5 | 5 | -8.2824 | 7370 | 7370 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.3** | 176.4 | 5 | 5 | -22.1568 | 7327 | 7327 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.4** | 193.2 | 5 | 5 | -30.4824 | 7272 | 7272 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.5** | 210.0 | 5 | 5 | -33.2568 | 7212 | 7212 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.6** | 226.8 | 5 | 5 | -30.4824 | 7148 | 7148 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.7** | 243.6 | 5 | 5 | -22.1568 | 7079 | 7079 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.8** | 260.4 | 5 | 5 | -8.2824 | 6999 | 6999 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.9** | 277.2 | 5 | 5 | 12.0432 | 6922 | 6922 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **Support** | 291.0 | 5 | 4 | 25.6116 | 6844 | 5475 | 38.28 | 47.40 | 31.80 | 34.76 | -42.13 |
| Span 3 | **Support** | 297.0 | 5 | 4 | 25.3668 | 6742 | 5393 | 38.28 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.1** | 305.8 | 5 | 5 | 15.1068 | 6572 | 6572 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.2** | 317.6 | 5 | 5 | -3.6576 | 6545 | 6545 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.3** | 329.4 | 5 | 5 | -16.6068 | 6522 | 6522 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.4** | 341.2 | 5 | 5 | -25.8576 | 6484 | 6484 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.5** | 353.0 | 5 | 5 | -31.4076 | 6443 | 6443 | 47.85 | 47.40 | 31.80 | 34.76 | -42.13 |
| | **0.6** | 364.8 | 5 | 5 | -33.2568 | 6398 | 6398 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.7** | 376.6 | 5 | 5 | -31.2264 | 6345 | 6345 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.8** | 388.4 | 5 | 5 | -25.1328 | 6287 | 6287 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **0.9** | 400.2 | 5 | 5 | -14.9760 | 6225 | 6225 | 47.85 | 8.00 | 31.80 | 6.00 | -42.13 |
| | **Support** | 410.5 | 5 | 4 | -2.7900 | 6174 | 4940 | 38.28 | 8.00 | 31.80 | 6.00 | -42.13 |

*** Area of mild steel based on minimum seismic requirement only (Remaining limit state requirements need to be satisfied; $A_{st,top}$ = 56.6 in$^2$ at right face of Bent 2)**

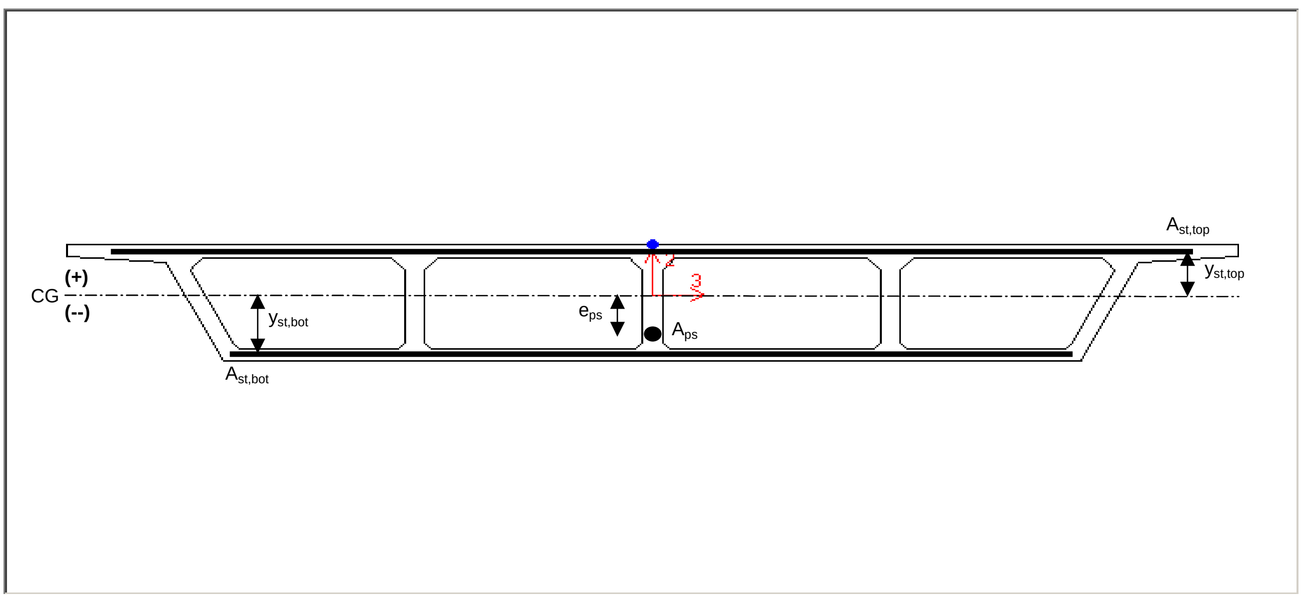


Table 1.8 Moment Demand Vs. Capacity

## Moment Capacity Check

| | Location | | Moment Demand | | Moment Capacity | | D/C Ratio | |
|---|---|---|---|---|---|---|---|---|
| | | | $M_{positive}$ | $M_{negative}$ | $M_{positive}$ | $M_{negative}$ | $M_{positive}$ | $M_{negative}$ |
| **Span 1** | **Support** | 1.5 | 1265 | 403 | 34530 | -39444 | 0.04 | 0.00 |
| | **0.1** | 12.6 | 11199 | 6847 | 54933 | -34040 | 0.20 | 0.00 |
| | **0.2** | 25.2 | 19313 | 11260 | 65503 | -23133 | 0.29 | 0.00 |
| | **0.3** | 37.8 | 24533 | 12766 | 72025 | -16558 | 0.34 | 0.00 |
| | **0.4** | 50.4 | 26883 | 11365 | 73892 | -14352 | 0.36 | 0.00 |
| | **0.5** | 63.0 | 26213 | 7057 | 86109 | -36067 | 0.30 | 0.00 |
| | **0.6** | 75.6 | 22801 | -159 | 81016 | -41879 | 0.28 | 0.00 |
| | **0.7** | 88.2 | 16352 | -10281 | 71684 | -51573 | 0.23 | 0.20 |
| | **0.8** | 100.8 | 7724 | -23310 | 58705 | -65648 | 0.13 | 0.36 |
| | **0.9** | 113.4 | -4742 | -39254 | 38646 | -85898 | 0.00 | 0.46 |
| | **Support** | 123.0 | -10597 | -45750 | 26587 | -81787 | 0.00 | 0.56 |
| **Span 2** | **Support** | 129.0 | -3820 | -52025 | 26432 | -81933 | 0.00 | 0.63 |
| | **0.1** | 142.8 | 6518 | -37436 | 41672 | -82802 | 0.16 | 0.45 |
| | **0.2** | 159.6 | 20082 | -14848 | 63619 | -60763 | 0.32 | 0.24 |
| | **0.3** | 176.4 | 28301 | 2571 | 77024 | -45653 | 0.37 | 0.00 |
| | **0.4** | 193.2 | 32005 | 14824 | 71217 | -17311 | 0.45 | 0.00 |
| | **0.5** | 210.0 | 30324 | 21911 | 73881 | -14256 | 0.41 | 0.00 |
| | **0.6** | 226.8 | 31905 | 15707 | 71218 | -17293 | 0.45 | 0.00 |
| | **0.7** | 243.6 | 28493 | 3950 | 77020 | -45591 | 0.37 | 0.00 |
| | **0.8** | 260.4 | 20536 | -12970 | 63615 | -60698 | 0.32 | 0.21 |
| | **0.9** | 277.2 | 7256 | -35054 | 41623 | -82794 | 0.17 | 0.42 |
| | **Support** | 291.0 | -3002 | -49702 | 26344 | -81924 | 0.00 | 0.61 |
| **Span 3** | **Support** | 297.0 | -9431 | -43914 | 26540 | -81708 | 0.00 | 0.54 |
| | **0.1** | 305.8 | -4979 | -38571 | 38316 | -86086 | 0.00 | 0.45 |
| | **0.2** | 317.6 | 6138 | -24116 | 58628 | -65419 | 0.10 | 0.37 |
| | **0.3** | 329.4 | 13804 | -12224 | 71666 | -51881 | 0.19 | 0.24 |
| | **0.4** | 341.2 | 19533 | -2881 | 80998 | -41529 | 0.24 | 0.07 |
| | **0.5** | 353.0 | 22619 | 3913 | 86086 | -35585 | 0.26 | 0.00 |
| | **0.6** | 364.8 | 23273 | 8159 | 74193 | -13993 | 0.31 | 0.00 |
| | **0.7** | 376.6 | 21298 | 9857 | 72006 | -16314 | 0.30 | 0.00 |
| | **0.8** | 388.4 | 16799 | 9006 | 65484 | -22996 | 0.26 | 0.00 |
| | **0.9** | 400.2 | 9760 | 5606 | 54917 | -34070 | 0.18 | 0.00 |
| | **Support** | 410.5 | 1199 | 404 | 34611 | -39346 | 0.03 | 0.00 |

Table 1.9 Shear Demand Vs. Capacity

## Shear Capacity Check

| | Location | | Shear Demand | Shear Capacity = Governing Shear Demand* | D/C Ratio |
|---|---|---|---|---|---|
| | | | $V_{max}$ | $\phi V_{n} = V_{u,\ limit\ state}$ | D/C |
| **Span 1** | **Support** | 1.5 | 803 | 2851 | 0.28 |
| | **0.1** | 12.6 | 772 | 2317 | 0.33 |
| | **0.2** | 25.2 | 540 | 1687 | 0.32 |
| | **0.3** | 37.8 | 309 | 1101 | 0.28 |
| | **0.4** | 50.4 | 227 | 681 | 0.33 |
| | **0.5** | 63.0 | 457 | 1207 | 0.38 |
| | **0.6** | 75.6 | 688 | 1782 | 0.39 |
| | **0.7** | 88.2 | 918 | 2341 | 0.39 |
| | **0.8** | 100.8 | 1149 | 2901 | 0.40 |
| | **0.9** | 113.4 | 1383 | 3596 | 0.38 |
| | **Support** | 123.0 | 1282 | 3966 | 0.32 |
| **Span 2** | **Support** | 129.0 | 1464 | 4378 | 0.33 |
| | **0.1** | 142.8 | 1498 | 3759 | 0.40 |
| | **0.2** | 159.6 | 1192 | 2961 | 0.40 |
| | **0.3** | 176.4 | 884 | 2160 | 0.41 |
| | **0.4** | 193.2 | 577 | 1399 | 0.41 |
| | **0.5** | 210.0 | 269 | 686 | 0.39 |
| | **0.6** | 226.8 | 546 | 1375 | 0.40 |
| | **0.7** | 243.6 | 853 | 2139 | 0.40 |
| | **0.8** | 260.4 | 1161 | 2942 | 0.39 |
| | **0.9** | 277.2 | 1496 | 3792 | 0.39 |
| | **Support** | 291.0 | 1440 | 4367 | 0.33 |
| **Span 3** | **Support** | 297.0 | 1234 | 3760 | 0.33 |
| | **0.1** | 305.8 | 1336 | 3388 | 0.39 |
| | **0.2** | 317.6 | 1116 | 2817 | 0.40 |
| | **0.3** | 329.4 | 900 | 2312 | 0.39 |
| | **0.4** | 341.2 | 684 | 1774 | 0.39 |
| | **0.5** | 353.0 | 468 | 1238 | 0.38 |
| | **0.6** | 364.8 | 252 | 738 | 0.34 |
| | **0.7** | 376.6 | 259 | 1000 | 0.26 |
| | **0.8** | 388.4 | 476 | 1548 | 0.31 |
| | **0.9** | 400.2 | 692 | 2138 | 0.32 |
| | **Support** | 410.5 | 743 | 2653 | 0.28 |

***Shear demand base on governing limit state requirement as determined by CTBridge**

## II.E Final Displacement Demand Assessment

The displacement demands are calculated in transverse and longitudinal direction using push over analyses. No additional global analysis is required to estimate the demand for this bridge for this per SDC section 2.2.1 and 5.2.1.

## II.F. Joint Shear Design

In a ductility based design approach for concrete structures, connections are key elements that must have adequate strength to maintain structure integrity under seismic loading. In moment resisting connections, the force transfer across the joint typically results in sudden changes in the magnitude and nature of moments, resulting in significant shear forces in the joint. Such shear forces inside the joint can be many times greater than the shear forces in individual components meeting at the joint.

According to the Seismic Design Criteria, the moment resisting connections between the superstructure and the column shall be designed to transfer the maximum forces produced when the column has reached its overstrength capacity, $M_0^{col}$. Additionally, the effects of overstrength shear $V_0^{col}$ will be considered.

According to the SDC (Sec 7.4.3), the following types of superstructure-to-substructure joints are considered T joints for the purpose of joint stress:

- Integral interior joints of a multi-column bents in the transverse direction
- All column/superstructure joints in the longitudinal direction.
- Exterior column joints for box girder superstructure if the cap beam extends beyond the joint far enough to develop the longitudinal cap reinforcement.

Other typical types of superstructure-to-substructure connections are knee and outrigger joints depending upon if the cap terminates within the box girder or it extends beyond it.

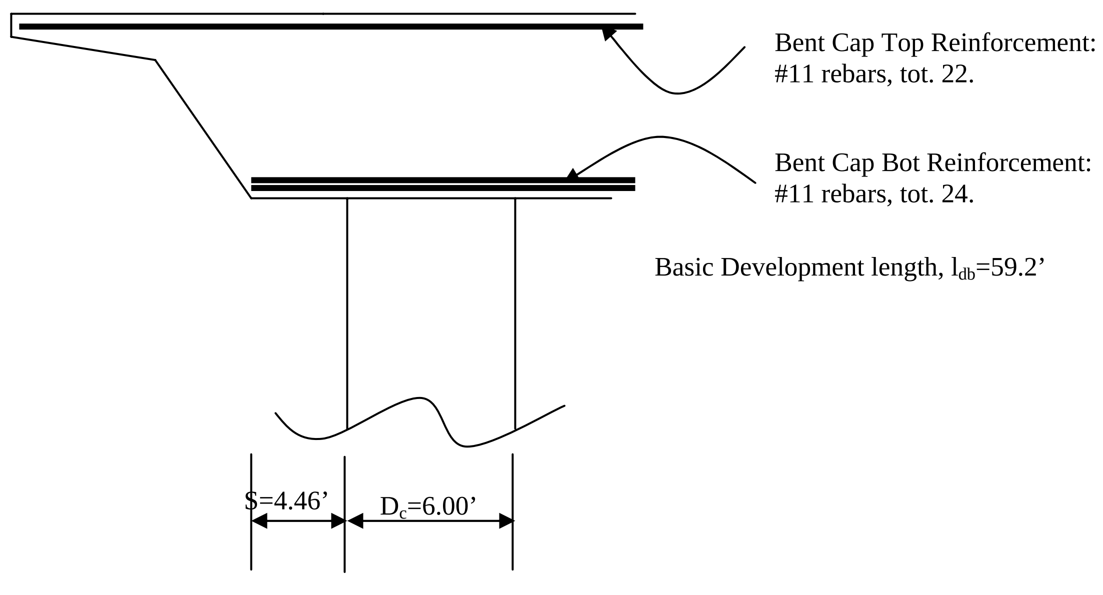



**Figure 13 Bent Cap-to-Column Joint**

**Since the cap main reinforcement does not extend beyond the diameter of the column, $D_c$, the column to cap joint cannot be characterized as T-joint for transverse bending. Instead, it will be analyzed as knee-joint**.

## II.F.1. Transverse Direction (Knee Joint)

The procedure and guidelines used herein are based on SDC recommendations for T-joints along with additional recommendations from the SDC Joint Shear Work Team and the paper entitled, "Knee-Joint Shear Design Guidelines – DRAFT". A knee joint is defined as any exterior column joint where the cap beam short stub length, *S*, is less than the diameter of the column, $D_c$, or less than the development length of the main bent cap reinforcement, $l_d$.

$$S < D_c \qquad \text{or} \qquad S < l_d$$

In general, there are two cases that need to considered:

Case1: $S < \frac{D_c}{2}$

Case2: $\frac{D_c}{2} < S < D_c \; or \quad l_d$

In our case $S = 4.42' > \frac{6.00'}{2}$, therefore it is classified as Case 2 knee joint.

Knee joints can fail in both opening and closing modes. Therefore, both loading conditions will be evaluated.

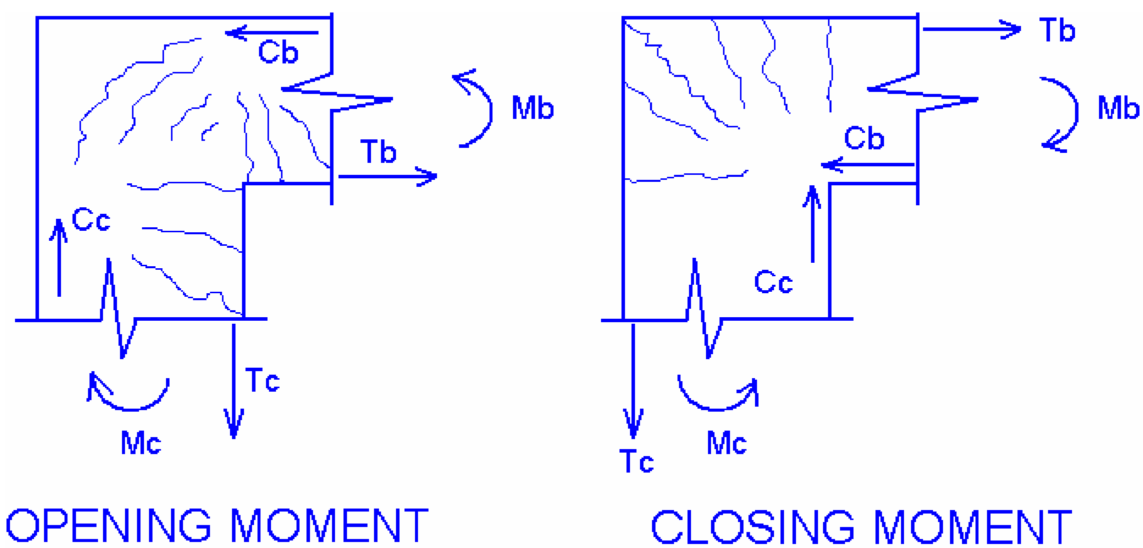



**Figure 14 Knee Joint Failure Modes**

In the opening moment, a series of arch-shaped cracks tends to form between the compression zones at the outside of the column and top of the beam. The intersection of the arch strut and the flexural compression zones at the top of the beam create outward-acting resultant forces. If the beam bottom reinforcement is anchored only by straight bar extension, there is nothing to resist the horizontal resultant tensile force. It will cause vertical splitting, reducing competence of the anchorage of the outer column rebars and beam top rebars.

Under the closing moment, a fan –shaped pattern of cracks develops, radiating from the outer surfaces of beam and column toward the inside. If there is no vertical reinforcement, clamping the beam top reinforcement into the joint, the entire beam tension, $T_b$, is transferred to the back of the joint as there is no mechanism to resist the moment at the base of the wedge shaped concrete elements caused by tension transfer to the concrete by bond.

Let us consider Bent 2 Knee Joint *Closing* Mode Failure.

Given:

Concrete compressive strength, $f_c' = 4{,}000\ psi$

Superstructure depth, $D_s = 6.75\ ft$

Column diameter, $D_c = 6\ ft$

Column reinforcement:

- Main reinforcement: #14 bars, total 26 giving $A_{st} = 58.50\ in^2$.
- Transverse reinforcement: #8 hoops at 5” c/c.

Concrete cover= $2\ in$

Column main reinforcement embedment length into the bent cap, $l_{ac} = 66\ in$

Bent cap width, $B_{cap} = 96\ in$

Column plastic moment, $M_p = 14{,}964\ ft-kip$ *

Column axial force (including the effect of overturning), $P_c = 2{,}474\ k$ *

Cap Beam main reinforcement

- Top:#11 bars, total 22.
- Bottom: #11 bars, total 24.

*These values are obtained from the *xSECTION* and *wFRAME* pushover analysis of Bent 2 and are listed on page 17.

Calculate principal stresses, $p_t \text{ and } p_c$

- Vertical shear stress, $v_{jv} = \frac{T_c}{A_{jv}}$

$A_{jv} = l_{ac} \times B_{cap}$ where $l_{ac} =$ Anchorage of column rebars into the bent cap.
$B_{cap} =$ Bent Cap Width.

The tensile stress resultant in the column, $T_{c,}$ corresponding to the column overstrength moment, $M_0$ is obtained to be *1.2 x 2862 kips = 3,434 kips* using *xSECTION* results. See Appendix W.

$$A_{jv} = l_{ac} \times B_{cap} = 66 \times 96 = 6{,}336\ in^2$$

$$\therefore v_{jv} = \frac{3{,}434}{6336} = 0.542\ ksi$$

- Nominal vertical stress,

$$f_v = \frac{P_c}{A_{jh}} = \frac{P_c}{\left(D_c + (2 \times \frac{D_s}{2})\right) \times B_{cap}} = \frac{2{,}474/1000}{\left(6.00 + (2 \times \frac{6.75}{2})\right) \times 8.00/144} = 0.168\ ksi$$

- Nominal horizontal stress

$$f_h = \frac{P_b}{B_{cap} \times D_s} = \frac{0}{8.00 \times 6.75} = 0.00$$

Since no prestressing is specifically designed to provide horizontal joint compression, it is assumed that $P_b = 0$.

Now the principal stresses are calculated.

$$p_t = \frac{(0.00 + 0.168)}{2} - \sqrt{\left(\frac{0.00 - 0.168}{2}\right)^2 + 0.542^2} = -0.464\ ksi$$

The negative sign indicates that the joint is under nominal principal tensile stresses.

$$p_c = \frac{(0.00+0.168)}{2} + \sqrt{\left(\frac{0.00-0.168}{2}\right)^2 + 0.542^2} = 0.632\ ksi$$

<u>Check the Joint Size Adequacy</u>

According to SDC (Section 7.4.2), all superstructure to column moment resisting joints shall be proportioned so that the principal stresses satisfy the following requirements:

Principal compression, $p_c \le 0.25 \times f_c'$ $(ksi)$ SDC Equation (7.8)

Principal tension, $p_t \le 12 \times \sqrt{f_c'}$ $(psi)$ SDC Equation (7.9)

In our case,

Principal compression, $p_c = 0.632 ksi \le 0.25 \times 4.0 = 1.0\ ksi$ OK

Principal tension, $p_t = 0.464\ ksi < 12 \times \sqrt{4000}/1000 = 0.76\ ksi$ OK

Therefore, the bent cap-to-column joint satisfies the SDC joint proportioning requirements.

<u>Check the Need for Additional Joint Requirement</u>

According to the SDC, if the principal tensile stress, $p_t \le 3.5 \times \sqrt{f_c'}\ (psi)$, no additional joint reinforcement is required. If no additional joint reinforcement is needed, then the volumetric ratio of transverse column reinforcement $\rho_s$ continued into the cap shall not be less that

$$\rho_{s,\min} = \frac{3.5 \times \sqrt{f_c'}}{f_{yh}} \quad (psi)$$ SDC Equation (7.18)

Since in our case $p_t = 0.464\ ksi > 3.5 \times \sqrt{4000}/1000 = 0.221\ ksi$, additional joint reinforcement will be necessary.

Similar calculations can be performed for Bent 3.

Let us now evaluate the same Bent 2 Knee Joint for the *Opening* Mode Failure.

Given:

From the *wFRAME* push-over analysis results,

Column plastic moment, $M_p = 12{,}636\ ft-kip$ *

Column axial force (including the effect of overturning), $P_c = 907\ kip$ *

Cap Beam main reinforcement

- Top:#11 bars, total 22.
- Bottom: #11 bars, total 24.

<u>Calculate principal stresses, $p_t$ *and* $p_c$</u>

- Vertical shear stress, $v_{jv} = \dfrac{T_c}{A_{jv}}$

The tensile stress resultant in the column, $T_{c,}$ corresponding to the column overstrength moment, $M_0$ is obtained to be *1.2 x 3,148 kips = 3,778 kips* using *xSECTION* results.

$$A_{jv} = 66 \times 96 = 6336\ in^2$$

$$\therefore v_{jv} = \frac{3,778}{6,336} = 0.596\ ksi$$

- Nominal vertical stress,

$$f_v = \frac{P_c}{A_{jh}} = \frac{P_c}{\left(D_c + (2 \times \frac{D_s}{2})\right) \times B_{cap}} = \frac{907}{\left(6.00 + (2 \times \frac{6.75}{2})\right) \times 8.00 \times 144} = 0.062\ ksi$$

- Nominal horizontal stress

$$f_h = \frac{P_b}{B_{cap} \times D_s} = \frac{0}{8.00 \times 6.75} = 0.00$$

Since no prestressing is specifically designed to provide horizontal joint compression, we can assume that $P_b = 0$.

Now the principal stresses are calculated substituting these data.

$$p_t = \frac{(0.00 + 0.062)}{2} - \sqrt{\left(\frac{0.00 - 0.062}{2}\right)^2 + 0.596^2} = -0.566\ ksi$$

The negative sign indicates that the joint is under nominal principal tensile stresses.

$$p_c = \frac{(0.00 + 0.062)}{2} + \sqrt{\left(\frac{0.00 - 0.062}{2}\right)^2 + 0.596^2} = 0.628\ ksi$$

Check the Joint Size Adequacy

Principal compression, $p_c = 0.628\ MPa \le 0.25 \times 4.0 = 1.0\ ksi$ OK

Principal tension, $p_t = 0.566\ ksi < 12 \times \sqrt{4000}/1000 = 0.760\ ksi$ OK

Therefore, the bent cap-to-column joint satisfies the SDC joint proportioning requirements.

Check the Need for Additional Joint Reinforcement

According to the SDC, if the principal tensile stress, $p_t \le 3.5 \times \sqrt{f_c'}\ (psi)$, no additional joint reinforcement is required. If no additional joint reinforcement is needed, then the volumetric ratio of transverse column reinforcement $\rho_s$ continued into the cap shall not be less that

$$\rho_{s,\min} = \frac{3.5 \times \sqrt{f_c'}}{f_{yh}} \quad (psi) \qquad \text{SDC Equation (7.18)}$$

Since in our case $p_t = 0.566 ksi > 3.5 \times \sqrt{4000}/1000 = 0.221\ ksi$, additional joint reinforcement will be necessary.

Therefore, based upon joint stress condition evaluation for both closing and opening modes of failure, the joint needs additional joint reinforcement. Now refer to Figure 15.

Joint Shear Requirement

a.0) Continuous U-Bars (Refer to Figures 16 and 20)

The top and bottom main bent cap reinforcement shall be in the form of continuous U-bars. The minimum area of this type of reinforcement shall be 33% of the area of the main column reinforcement anchored into the bent cap. The splices in U-bars shall not be allowed within a distance $l_d$ beyond the interior face of the column.

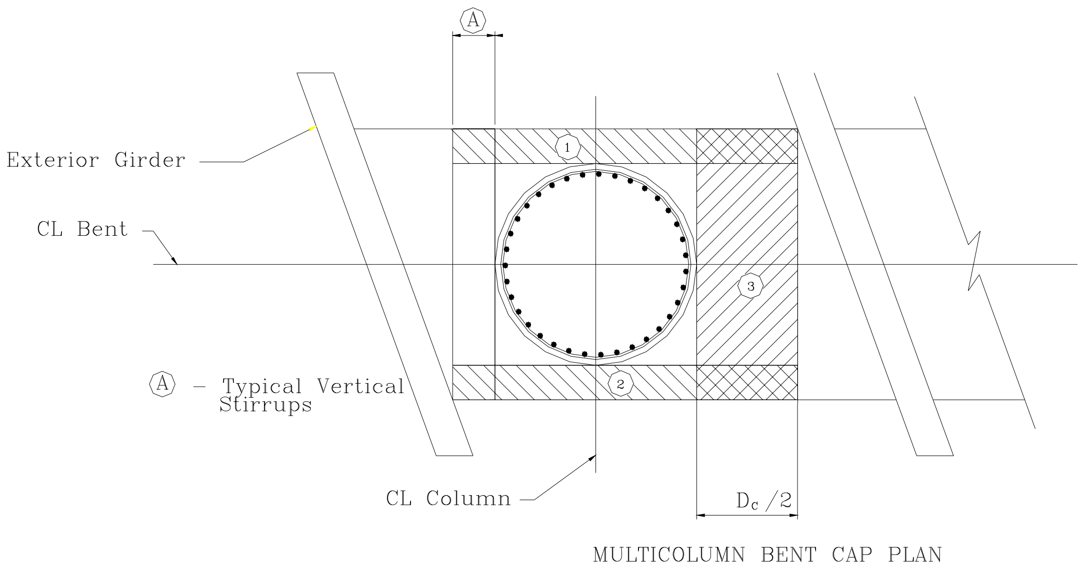



**Figure 15 Regions of Additional Joint Shear Reinforcement**

$$A_{s\ \ required}^{U-Bar} = 0.33 \times A_{st} = 0.33 \times 58.5 = 19.3\ in^2$$

The bent cap reinforcement based upon service and seismic loading consists of:

Top Reinforcement #11, total 22 bars giving $A_{st} = 34.32\ in^2$

Bottom Reinforcement #11, total 24 bars giving $A_{st} = 37.44\ in^2$

$$A_{s\ \ provided}^{U-Bar} = 12 \times 1.56 = 18.72\ in^2 \approx 19.3\ in^2$$ OK

See Figure 16 for rebar layout.

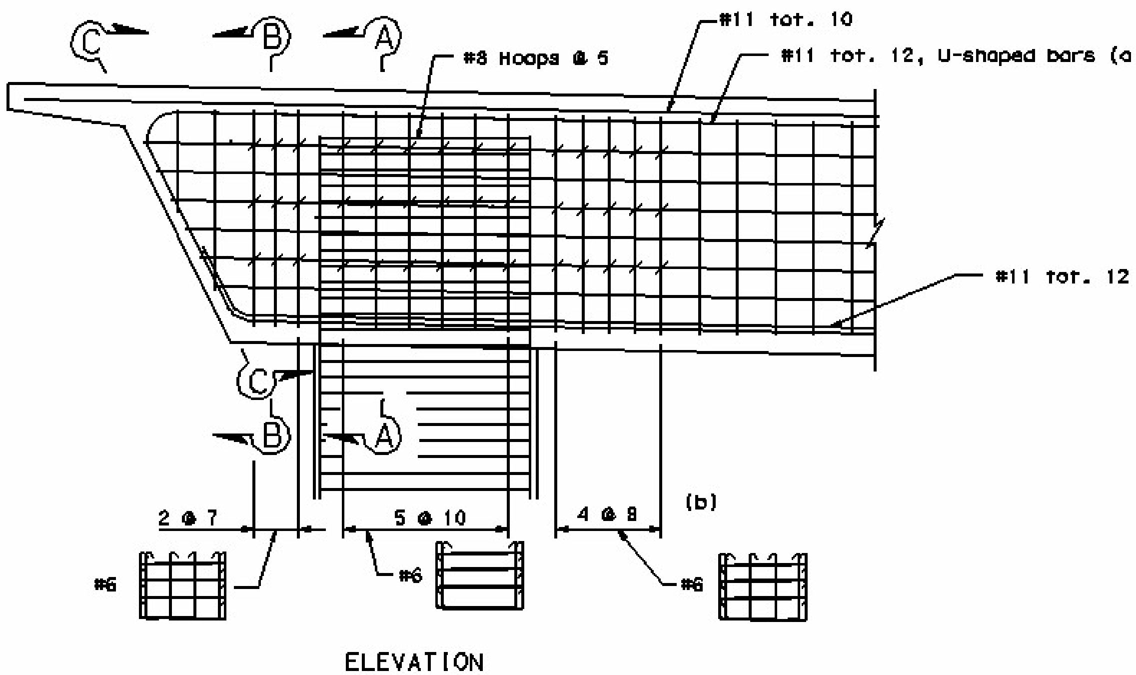



**Figure 16 Location of Joint Shear Reinforcement (Elevation View)**

a.1) Vertical Stirrups in Joint Region

Vertical stirrups or ties shall be placed transversally within region 3 as shown in Figure 15.

$$A_s^{jv} = 0.2 \times A_{st} \qquad \text{SDC Equation (7.19)}$$

where $A_{st}$ = Total area of column main reinforcement anchored in the joint.

In our case, the whole column main reinforcement i.e. #14, total 26, is anchored into the joint.

$$A_s^{jv}{}_{required} = 0.20 \times 58.5 = 11.7 in^2$$

Provide 5 sets of 6-legged ,#6 stirrups so that

$$A_s^{jv}{}_{provided} = (6\,legs)(5\,sets)(0.44) = 13.2 in^2 > 11.7 in^2 \qquad \text{OK}$$

These vertical stirrups and ties are placed transversely within a distance $\frac{D_c}{2}$ extending from the face of the column. The maximum stirrup spacing is:

$$s_{\max} = Lesser\ of \begin{cases} d/2 = 74/2 = 37in \\ 24in \end{cases}$$ BDS 8.19.3

where $d$ =distance of extreme compression fiber from the centroid of the tensile reinforcement. The $d$ = 74in value was calculated during the bent cap design. As shown in Figures 16 and 17, place 5 sets at 8 in c/c in region 3. These vertical stirrups are shown in Figure 16 and also as dots in Figure 17.

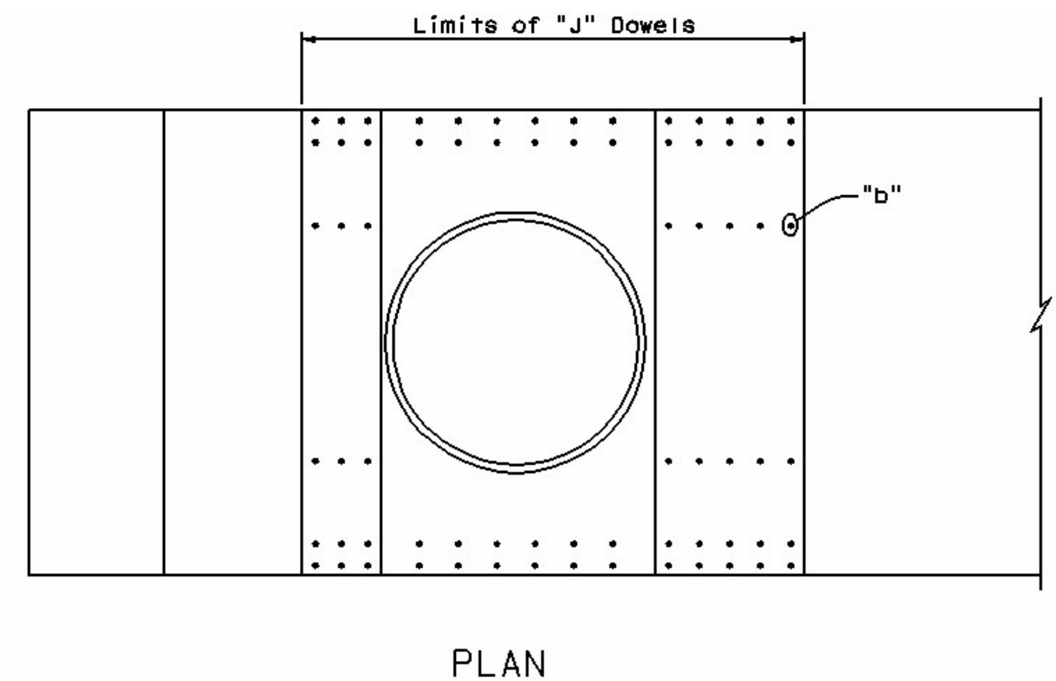



**Figure 17 Location of Vertical Stirrups (Elevation View)**

b) Horizontal Stirrups in Joint Region

Horizontal stirrups or ties shall be placed transversely around the vertical stirrups or ties in two or more intermediate layers vertically at not more than 18 in.

$$A_{s\ required}^{jh} = 0.1 \times A_{st}$$ SDC Equation (7.20)

$$A_{s\ required}^{jh} = 0.1 \times 58.5 = 5.85in^2$$

As shown in Figure 18, provide 3 legged #6 total 14 sets so that

$$A_{s\ provided}^{jh} = (3legs)(14sets)(0.44) = 18.48\ in^2 > 5.85\ in^2$$

This horizontal reinforcement shall be placed within a distance $D_c$ extending from either side of the column centerline as shown in Figure 16. These stirrups are in Figure 18.

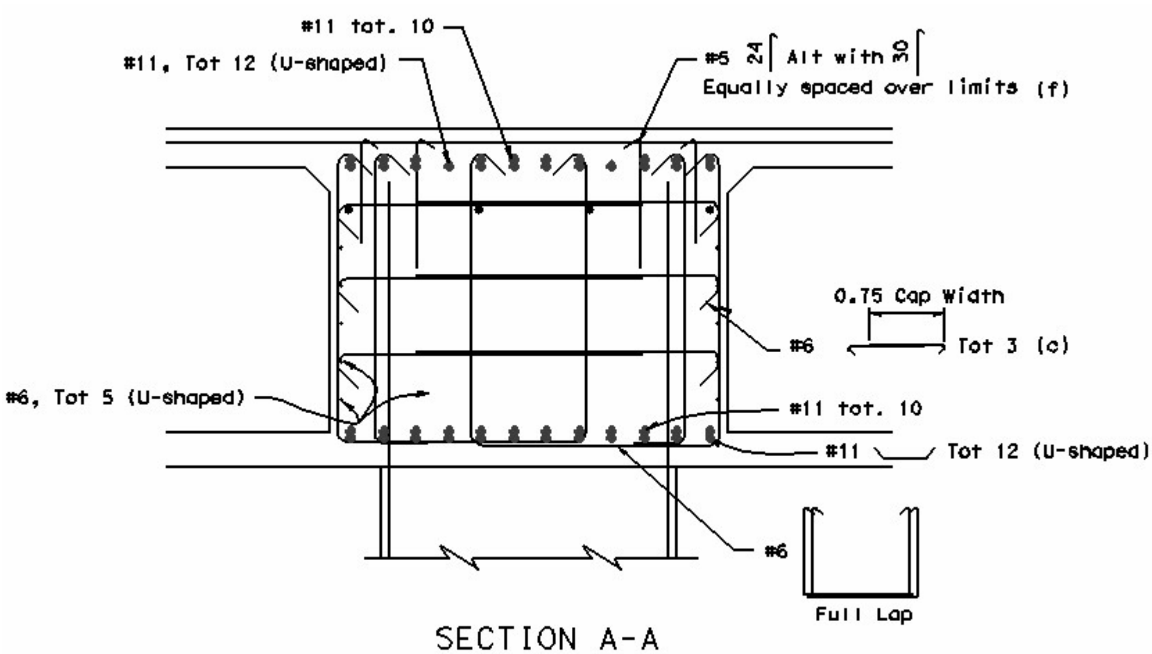



**Figure 18 Joint Reinforcement Within the Column Region**

c) Horizontal Side Reinforcement

According to the SDC (Section 7.4.4.3), the total longitudinal side face reinforcement in the bent cap shall be equal to the greater of the area specified by

$$A_s^{sf} \geq \begin{cases} 0.1 \times A_{cap}^{top} \\ \quad or \\ 0.1 \times A_{cap}^{bot} \end{cases} \quad \text{where } A_{cap} = \text{Area of bent cap top or bottom flexural steel.}$$

This side reinforcement shall be continuous around the joint end and placed near the side faces of the bent cap with a maximum spacing of 12 in. As shown in Figures 18 and 19, such horizontal reinforcement shall be in the form of continuous over the end face of the knee-joint. Splices in these continuous bars shall be located at least distance $l_d$ beyond the interior face of the column.

$$A_{cap}^{top} = 34.32\ in^2$$
$$A_{cap}^{bot} = 37.44\ in^2$$

$$A_s^{sf} \geq \begin{cases} 0.1 \times 34.32 = 3.43\ in^2 \\ \quad\quad or \\ 0.1 \times 37.44 = 3.74\ in^2 \end{cases}$$

As shown in Figures 18 and 19, provide #6, 5 continuous giving

$$A_{s\ provided}^{sf} = (10\,bars) \times 0.44 = 4.4\ in^2 \quad > \quad 3.74\ in^2.$$

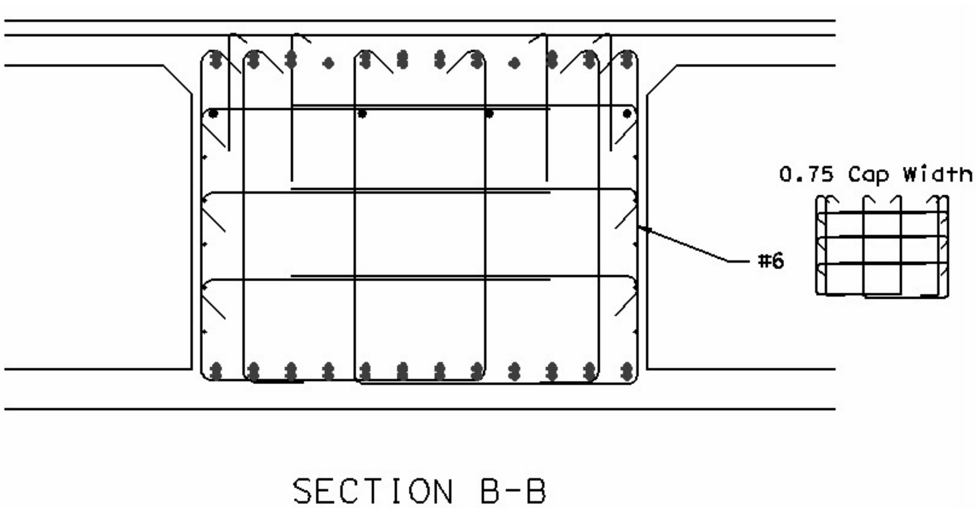



**Figure 19 Joint Reinforcement Outside the Column Region**

d) J-Dowels

According to the SDC Sec. 7.4.4.3, for bents skewed greater than $20^0$, J-dowels hooked around the longitudinal top deck steel extending alternatively 24 in and 30 in into the bent cap are required. This helps to prevent any potential delamination of concrete around deck top reinforcement. Although strictly following SDC guidelines, there is no need for J-Dowels for this bridge. Let us provide it anyway.

$$A_s^{j-bar} = 0.08 \times A_{st} = 0.08 \times 58.5 = 4.68\ in^2$$

Use 16, #5 J-Dowels.

$$A_{s\ provided}^{j-bar} = (16 bars) \times 0.31 = 4.96\ in^2 \quad > \quad 4.68\ in^2.$$

The J-Dowels will be uniformly placed within a rectangular region defined by the width of the bent cap and the distance $D_c$ on either side of the centerline of the column. These dowels are shown in Figures 18 and 19.

e) Transverse Reinforcement

According to the recommendations made by the Work Team on Joint Shear, the transverse reinforcement in the joint region shall consist of hoops with a minimum reinforcement ratio specified as

$$\rho_s = 0.4 \times \frac{A_{st}}{l_{ac}^{\ 2}}$$ SDC Equation (7.23),

$A_{st}$ = Area of longitudinal column reinforcement
$l_{ac=}$ = Anchorage length.

This requirement results in about 50% more steel than a similar case of T-joint. The Work Team felt that given the vulnerability of knee joints, such excessive transverse steel is justified.

$$\rho_{s\,required} = 0.4 \times \frac{58.5}{66^2} = 0.0054$$

Column transverse reinforcement that extends into the joint region consists of #8 hoops at 5 in spacing.

$$\rho_{s,\quad provided} = \frac{4 \times A_b}{D' \times s} = \frac{4 \times 0.79}{\left(72 - 2 \times 2 - 2 \times \dfrac{1.13}{2}\right) \times (5)} = 0.0094 \ > \ 0.0054$$

e) Anchorage for Main Column Reinforcement

According to the SDC, the main column reinforcement shall extend into the cap as deeply as possible in order to fully develop the compression strut mechanism in the joint.

If the joint shear reinforcement prescribed in SDC Section 7.4.4.2, and the minimum bar spacing requirements in the Bridge Design Specifications 8.21 are met, then the anchorage for longitudinal column bars developed into the cap beam for seismic loads shall not be less than the length specified as

$$l_{ac,\,required} = 24 d_{bl}$$ SDC Equation (8.1)

$$l_{ac,required} = 24 \times 1.69 = 40.6\ in$$

$$l_{ac,\ provided} = 66\ in > 40.6\ in$$ OK

It is important to note that as per the SDC requirements, the minimum anchorage length specified above cannot be reduced by adding hooks or mechanical anchorage devices. The reinforcement development requirements in BDS section 8.24 through 8.29 must also be satisfied for all cases other than seismic.

## II.F.ii Longitudinal (T-joint)

As determined earlier based upon SDC guidelines, the connection between the column and the bent cap is analyzed as a T-joint for longitudinal bending.

For longitudinal bending, the overturning effects on the column axial force are insignificant, and hence the column plastic moments due to dead load can be used. Let us calculate joint stresses for the tension column that will provide higher value of principal tensile stress, generally more critical than principal compressive stress.

Column plastic moment, $M_p = 13{,}827\ ft-kip$ *

Column axial force (including the effect of overturning), $P_c = 1{,}689\ kip$ *

Cap Beam main reinforcement

- Top Reinforcement: #11, total 22 bars
- Bottom Reinforcement #11, total 24 bars.

<u>Calculate principal stresses, $p_t$ and $p_c$</u>

- Vertical shear stress, $v_{jv} = \dfrac{T_c}{A_{jv}}$

The tensile stress resultant in the column, $T_{c,}$ corresponding to the column overstrength moment, $M_0$ is obtained to be *1.2 x 2,947 kips = 3,536 kips* using *xSECTION* results.

$$A_{jv} = l_{ac} \times B_{cap} = 66 \times 96 = 6{,}336 in^2$$

$$\therefore v_{jv} = \frac{3{,}536}{6{,}336} = 0.558\ ksi$$

- Nominal vertical stress,

$$f_v = \frac{P_c}{A_{jh}} = \frac{P_c}{(D_c + D_s) \times B_{cap}} = \frac{1{,}689}{(6.00 + 6.75) \times 8.00 \times 144} = 0.115\ ksi$$

- Nominal horizontal stress

Since no prestressing is specifically designed to provide horizontal joint compression, it is assumed that that $P_b = 0$.

$$f_h = \frac{P_b}{B_{cap} \times D_s} = \frac{0}{8.00 \times 6.75} = 0.00$$

Now the principal stresses are calculated substituting these data.

$$p_t = \frac{(0.00 + 0.115)}{2} - \sqrt{\left(\frac{0.00 - 0.115}{2}\right)^2 + 0.558^2} = -0.503\ ksi$$

The negative sign indicates that the joint is under nominal principal tensile stresses.

$$p_c = \frac{(0.00 + 0.115)}{2} + \sqrt{\left(\frac{0.00 - 0.115}{2}\right)^2 + 0.558^2} = 0.676\ ksi$$

<u>Check the Joint Size Adequacy</u>

Principal compression, $p_c = 0.676\ ksi \leq 0.25 \times 4.0 = 1.0\ ksi$ OK

Principal tension, $p_t = 0.503\ ksi < 12 \times \sqrt{4000}/1000 = 0.760\ ksi$ OK

Therefore, the bent cap-to-column joint satisfies the SDC joint proportioning requirements.

<u>Check the Need for Additional Joint Requirement</u>

According to the SDC 7.4.4.2, if the principal tensile stress, $p_t \leq 3.5 \times \sqrt{f_c'}\ (psi)$, no additional joint reinforcement is required. If no additional joint reinforcement is needed, then the volumetric ratio of transverse column reinforcement $\rho_s$ continued into the cap shall not be less that

$$\rho_{s,\min} = \frac{3.5 \times \sqrt{f_c'}}{f_{yh}} \quad (psi)$$ SDC Equation (7.18)

Since in our case $p_t = 0.503\ ksi > 3.5 \times \sqrt{4000}/1000 = 0.221\ ksi$, additional joint reinforcement will be necessary.

The horizontal stirrups, cap beam u-bar requirements, continuous cap side face reinforcement, j-dowels, and column reinforcement anchorage provided for the transverse bending will also satisfy the joint shear requirements for the longitudinal bending. The only additional joint reinforcement requirement that needs to be satisfied for the longitudinal bending is to provide vertical stirrups in Regions 1 and 2 of Figure

15. Additionally, different requirement for transverse reinforcement in the joint will be checked.

a) Vertical Stirrups in Joint Region – Regions 1 and 2 of Figure 15

$$A_s^{jv} = 0.2 \times A_{st} \qquad \text{SDC Equation (7.19)}$$

where $A_{st}$ = Total area of column main reinforcement anchored in the joint.

In our case, all the column main reinforcement i.e. #14, total 26 bars are anchored into the bent cap.

$$\therefore A_s^{jv}{}_{provided} = 0.2 \times 58.5 = 11.7\ in^2$$

Provide total 14 sets of 2 legged #6 stirrups or ties on each side of the column.

$$A_s^{jv} \text{ provided} = (2\,legs)(14\,sets)(0.44) = 12.32\ in^2 > 11.7\ in^2 \qquad \text{OK}$$

As shown in Figures 16 and 17, these vertical stirrups and ties are placed transversely within a distance $D_c$ extending from either side of the column centerline. The maximum stirrup spacing is:

$$s_{\max} = Lesser\ of \begin{cases} d/2 = 74/2 = 37\ in \\ 24\ in \end{cases} \qquad \text{BDS 8.19.3}$$

Note that in the overlapping portions of regions 1 and 2 with region 3, the outside two legs of the 6-legged vertical stirrups provided for transverse bending are also counted towards two legs of the vertical stirrups required for the longitudinal bending.

<u>Transverse Reinforcement</u>

According to the SDC, the transverse reinforcement in a T-joint joint region shall consist of hoops with a minimum reinforcement ratio specified as:

$$\rho_{s\,required} = 0.4 \times \frac{A_{st}}{l_{ac}^2} \quad (in) \qquad \text{SDC Equation (7.23)}$$

Also, all vertical bars shall be extended to within 12 in from the deck top, so

$$\rho_s = 0.4 \times \frac{58.5}{66^2} = 0.0054$$

As calculated above for transverse bending

$$\rho_{s,\ provided} = 0.0094 > 0.0054 \qquad \text{OK}$$

## II.G Torsional Capacity Check

The torsional effects in the bent cap beam under the longitudinal bending are well resisted by this integral bent cap that is clamped by the box girder superstructure on each side. If the superstructure remains elastic under the longitudinal bending (It will be assured that such is the case by making sure that the superstructure satisfies MTD 20-6 requirements – to be done in a subsequent section), it is difficult to expect torsional distress of cap beams, as the torsional rotations of the bent cap would require significant distortions and warping of the superstructure. Such rotations will be resisted by in-plane membrane forces in the deck and soffit slab. Additionally, there is no history of any damage to bent caps from previous earthquakes for integral bent caps. For these reasons, the torsional capacity of the cap beam is assumed to be adequate and not checked.

## II.H. Abutment Seat Width Design

The bridge is supported on seat type abutment. It is CalTrans design philosophy to provide adequate seat width so that the superstructure does not fall-off during the anticipated seismic shaking. As per SDC (7.8.3), sufficient seat width shall be available to accommodate the anticipated thermal movement, prestress shortening, creep, shrinkage, and the relative longitudinal earthquake displacement.

$$N_A \geq \Delta_{p/s} + \Delta_{cr+sh} + \Delta_{temp} + \Delta_{eq} + 4 \qquad (in)$$

Where

$N_A =$ Abutment seat width normal to the centerline of the bearing.

$\Delta_{p/s} =$ Pre-stress-shortening

$\Delta_{cr+sh} =$ Creep and shrinkage

$\Delta_{eq} =$ The largest relative earthquake displacement between the superstructure and the abutment. Such demand can be estimated either by global or stand-alone analysis.

The minimum seat width calculated above is normal to the centerline of bearing and in no case shall be less than 30 in.

$N_{A,provided} = 36in \quad > \quad 30in$ OK

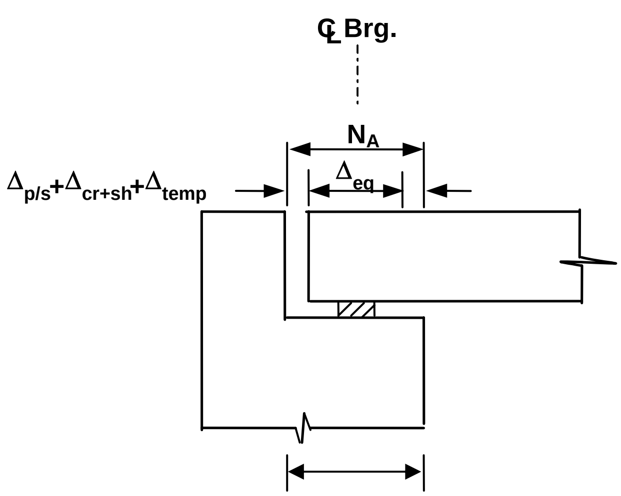



**Figure 21 Minimum Abutment Seat Width**

The combined effect of $\Delta_{p/s}, \Delta_{cr+sh}, \Delta_{temp}$ is calculated using JOINT MOVEMENT CALCULATIONS form placed in Appendix O to be 2.5 in.

The maximum seismic demand along the longitudinal direction of the bridge is calculated in a conservative way assuming that maximum longitudinal and transverse (along the bent line) displacement occur simultaneously so that

$$\Delta_{longitudinal} = 15.11 + 15.25 \times \sin(20^0) = 20.3\ in$$

$$\Delta_{normal\ to\ bearing\ centerline} = 20.3 \times \cos(20^0) = 19\ in$$

$$\Delta_{A\ required} = 19 + 2.5 \times \cos(20^0) + 4 = 25.4 in < 30 in.$$

## II.I. No Splice Zone

Memo-to-Designers 20-9 deals with the issue of splices in bar reinforcing steel. In general any rebar longer than the standard 18m will need to be spliced. The type of splice depends upon whether the component is deemed as "seismic-critical" or not. As defined in MTD 20-9, seismic critical member elements are expected to undergo significant post-elastic deformations during a seismic event. For prototype bridge, only columns have been designated as "seismic critical" elements.

In our case, maximum length of column rebar can be estimated as

$L_{max}$= 44.00 + 5.5 = 49.5 ft < 60.00 ft

Therefore, we will specify on the plans that no splices will be permitted for column main rebars. The superstructure rebars, however, will need be spliced. As per MTD20-6, "Service Splice" will be used to splice such rebars. It is good design practice, however, to also specify no splice zone up to the point of contraflexure, determined as per guidelines in MTD 20-6.

# APPENDIX - A

(Selective Portions of CTBRIDGE Input)

## Input Summary

### Cross Section Shape Information

| **Box Girder 1 data** | | **Shape:** | **Box Girder** |
|---|---|---|---|
| Overall Width: 706.00 in | Top Slab Thickness: | 9.13 in | |
| Overall Depth: 81.00 in | Bottom Slab Thickness: | 8.25 in | |
| Left Overhang Width: | 60.00 in | Right Overhang Width: | 60.00 in |
| Left Overhang Inside Thickness: | 12.00 in | Right Overhang Inside Thickness: | 12.00 in |
| Left Overhang Outside Thickness: | 8.00 in | Right Overhang Outside Thickness: | 8.00 in |
| Left Exterior Web Offset: | 34.50 in | Right Exterior Web Offset: | 34.50 in |
| Left Exterior Web Thickness: | 12.00 in | Right Exterior Web Thickness: | 12.00 in |
| Top Fillet Width: | 4.00 in | Top Fillet Depth: | 4.00 in |
| Bottom Fillet Width: | 0.00 in | Bottom Fillet Depth: | 0.00 in |
| Web Spacing Type: | Symmetrical | Number of Interior Webs: | 3 |
| Interior Web Thickness: | 12.00 in | Interior Web Distance: | 144.00 in |
| Interior Web 1 Thickness: | 12.00 in | Interior Web 1 Distance: | 114.50 in |
| Interior Web 2 Thickness: | 12.00 in | Interior Web 2 Distance: | 144.00 in |
| Interior Web 3 Thickness: | 12.00 in | Interior Web 3 Distance: | 144.00 in |

| Box Girder 1 properties | | | Gross | Factor | Cracked |
|---|---|---|---|---|---|
| CG to Top | 35.24 in | Area: | 14902.38 in² | X 1.000 | 14902.38 in² |
| CG to Bottom | 45.76 in | Ixx: | 15160037.03 in4 | X 1.000 | 15160037.03 in4 |
| CG to Left | 353.00 in | Iyy: | 533747046.76 in4 | X 1.000 | 533747046.76 in4 |
| CG to Right | 353.00 in | Torsion: | 45022802.56 in4 | X 1.000 | 45022802.56 in4 |

| **Box Girder 2 data** | | **Shape:** | **Box Girder** |
|---|---|---|---|
| Overall Width: | 706.00 in | Top Slab Thickness: | 9.13 in |
| Overall Depth: | 81.00 in | Bottom Slab Thickness: | 12.00 in |
| Left Overhang Width: | 60.00 in | Right Overhang Width: | 60.00 in |
| Left Overhang Inside Thickness: | 12.00 in | Right Overhang Inside Thickness: | 12.00 in |
| Left Overhang Outside Thickness: | 8.00 in | Right Overhang Outside Thickness: | 8.00 in |
| Left Exterior Web Offset: | 34.50 in | Right Exterior Web Offset: | 34.50 in |
| Left Exterior Web Thickness: | 12.00 in | Right Exterior Web Thickness: | 12.00 in |
| Top Fillet Width: | 4.00 in | Top Fillet Depth: | 4.00 in |
| Bottom Fillet Width: | 0.00 in | Bottom Fillet Depth: | 0.00 in |
| Web Spacing Type: | Symmetrical | Number of Interior Webs: | 3 |
| Interior Web Thickness: | 12.00 in | Interior Web Distance: | 144.00 in |
| Interior Web 1 Thickness: | 12.00 in | Interior Web 1 Distance: | 114.50 in |
| Interior Web 2 Thickness: | 12.00 in | Interior Web 2 Distance: | 144.00 in |
| Interior Web 3 Thickness: | 12.00 in | Interior Web 3 Distance: | 144.00 in |

| **Box Girder 2 properties** | | | **Gross** | **Factor** | **Cracked** |
|---|---|---|---|---|---|
| CG to Top | 38.97 in | Area: | 16646.17 in² | X 1.000 | 16646.17 in² |
| CG to Bottom | 42.03 in | Ixx: | 17143559.87 in4 | X 1.000 | 17143559.87 in4 |
| CG to Left | 353.00 in | Iyy: | 571091004.60 in4 | X 1.000 | 571091004.60 in4 |
| CG to Right | 353.00 in | Torsion: | 50040498.04 in4 | X 1.000 | 50040498.04 in4 |

| **Circle 1 data** | **Shape:** | **Circle** |
|---|---|---|
| | Diameter: | 72.00 in |

| **Circle 1 properties** | | | **Gross** | **Factor** | **Cracked** |
|---|---|---|---|---|---|
| CG to Top | 36.00 in | Area: | 4071.50 in² | X 1.000 | 4071.50 in² |
| CG to Bottom | 36.00 in | Ixx: | 1319167.32 in4 | X 1.000 | 1319167.32 in4 |
| CG to Left | 36.00 in | Iyy: | 1319167.32 in4 | X 1.000 | 1319167.32 in4 |
| CG to Right | 36.00 in | Torsion: | 2638334.64 in4 | X 1.000 | 2638334.64 in4 |

## APPENDIX - A

(Selective Portions of CTBRIDGE Input) - Continues

### Material Information

| **Concrete 1 data** | | **Material:** | **Concrete** |
|---|---|---|---|
| Unit Weight: | 0.15 kip/ft | Poisson's Ratio: | 0.200 |
| | | Elastic Modulus (Ec): | 3834.25 ksi |
| Concrete Strength (f'c): | 4.00 ksi | Shear Modulus: | 1597.61 ksi |
| Initial Strength (fci): | 3.50 ksi | Initial Modulus (Eci): | 3586.62 ksi |

| **Steel 1 data** | | **Material:** | **Steel** |
|---|---|---|---|
| Unit Weight: | 0.49 kip/ft³ | Poisson's Ratio: | 0.300 |
| | | Elastic Modulus (Es): | 29000.00 ksi |
| Yield Strength (fy): | 60.00 ksi | Shear Modulus: | 11153.85 ksi |

| **Prestress 1 data** | | **Material:** | **Prestress Steel** |
|---|---|---|---|
| Unit Weight: | 0.49 kip/ft³ | Poisson's Ratio: | 0.300 |
| Ultimate Strength (fpu): | 270.00 ksi | Elastic Modulus (Ep): | 28500.00 ksi |
| Yield Strength (fpy): | 243.00 ksi | Shear Modulus: | 10961.54 ksi |

## Span Information

**Span 1 data**

Length: 126.00 ft

| **Effective Dimensions** | |
|---|---|
| Begin: | 1.50 ft |
| End: | 3.00 ft |
| Model As Link: | Yes |

| **Num** | **Distance** | **Section** | **Num** | **Distance** | **Section** |
|---|---|---|---|---|---|
| 1 | Begin | Box Girder 1 | 3 | 121.78 ft | Box Girder 2 |
| 2 | 105.78 ft | Box Girder 1 | 4 | End | Box Girder 2 |

| **Num** | **Distance** | **Material** | **Num** | **Distance** | **Material** |
|---|---|---|---|---|---|
| 1 | Begin | Concrete 1 | 2 | End | Concrete 1 |

**Placement of Results**
Evenly spaced: 10

**Placement of Nodes**
Evenly spaced: 4

**Span 2 data**

Length: 168.00 ft

| **Effective Dimensions** | |
|---|---|
| Begin: | 3.00 ft |
| End: | 3.00 ft |
| Model As Link: | Yes |

| **Num** | **Distance** | **Section** | **Num** | **Distance** | **Section** |
|---|---|---|---|---|---|
| 1 | Begin | Box Girder 2 | 4 | 147.78 ft | Box Girder 1 |
| 2 | 4.22 ft | Box Girder 2 | 5 | 163.78 ft | Box Girder 2 |
| 3 | 20.22 ft | Box Girder 1 | 6 | End | Box Girder 2 |

| **Num** | **Distance** | **Material** | **Num** | **Distance** | **Material** |
|---|---|---|---|---|---|
| 1 | Begin | Concrete 1 | 2 | End | Concrete 1 |

**Placement of Results**
Evenly spaced: 10

**Placement of Nodes**
Evenly spaced: 4

# APPENDIX - A

(Selective Portions of CTBRIDGE Input) - Continues

**Span 3 data**

Length: 118.00 ft

**Effective Dimensions**

Begin: 3.00 ft
End: 1.50 ft
Model As Link: Yes

| Num | Distance | Section |
|---|---|---|
| 1 | Begin | Box Girder 2 |
| 2 | 4.26 ft | Box Girder 2 |
| 3 | 20.22 ft | Box Girder 1 |
| 4 | End | Box Girder 1 |

| Num | Distance | Material |
|---|---|---|
| 1 | Begin | Concrete 1 |
| 2 | End | Concrete 1 |

**Placement of Results**
Evenly spaced: 10

**Placement of Nodes**
Evenly spaced: 4

## Column Type Information

**Column Type 1 data**

**Datum: Bottom**

| Num | Distance | Section |
|---|---|---|
| 1 | Bottom | Circle 1 |
| 2 | Top | Circle 1 |

| Num | Distance | Material |
|---|---|---|
| 1 | Bottom | Concrete 1 |
| 2 | Top | Concrete 1 |

**Placement of Results**
Evenly spaced: 4

**Placement of Nodes**
Evenly spaced: 4

## Bent Information

**Bent 2 data**

Skew Angle: 20.0000 °

Continuous Connection

Condition: Fix

**Bent 2, Column 1**

**Dist in Bent -17.00 ft**
Rotation: 0.0000 °

Column Type: Column Type 1

Column top placed at bent bottom

Top Elev: 82.02 ft
Bot Elev: 38.02 ft

Height defined by column length
Length: 44.00 ft
Bottom Condition: Pin

**Bent 2, Column 2**

**Dist in Bent 17.00 ft**
Rotation: 0.0000 °

Column Type: Column Type 1

Column top placed at bent bottom

Top Elev: 82.02 ft
Bot Elev: 38.02 ft

Height defined by column length
Length: 44.00 ft
Bottom Condition: Pin

**Bent 3 data**

| | | |
|---|---|---|
| | Skew Angle: | 20.0000 ° |
| Continuous Connection | Condition: | Fix |
| **Bent 3, Column 1** | **Dist in Bent** | **-17.00 ft** |
| | Rotation: | 0.0000 ° |
| Column Type: | Column Type 1 | |
| Column top placed at bent bottom | Top Elev: | 84.70 ft |
| | Bot Elev: | 37.70 ft |
| Height defined by column length | Length: | 47.00 ft |
| Bottom Condition: Pin | | |
| **Bent 3, Column 2** | **Dist in Bent** | **17.00 ft** |
| | Rotation: | 0.0000 ° |
| Column Type: | Column Type 1 | |
| Column top placed at bent bottom | Top Elev: | 84.70 ft |
| | Bot Elev: | 37.70 ft |
| Height defined by column length | Length: | 47.00 ft |
| Bottom Condition: Pin | | |

## Support Information

**Abut 1 data**

Skew Type: Skew Angle: 20.0000 °
Connection to Span(s): Continuous Spans Connection Type: Roller

**Abut 4 data**

Skew Type: Skew Angle: 20.0000 °
Connection to Span(s): Continuous Spans Connection Type: Roller

## Dead Load

**Dead load is active** **Self weight is applied**

## Added Dead Load

**Additional dead load is active** **Wearing surface is applied**
Wearing Surface: 35.00 psf Deck Width: 56.00 ft

| Load Name | Start Magnitude | End Magnitude | Start Distance | End Distance | Load Type | Load Direction | Applied To |
|---|---|---|---|---|---|---|---|
| Type 732 Barrier ... | 0.82 kip/ft | 0.82 kip/ft | 0.000 ratio | 1.000 ratio | Distributed Force | Gravity | Span 1<br>Span 2<br>Span 3 |

## Dead Load - Unfactored Forces - Columns

**Bent 2, Column 1**

| Location<br>ft | AX<br>kip | VY<br>kip | VZ<br>kip | TX<br>kip·ft | MY<br>kip·ft | MZ<br>kip·ft |
|---|---|---|---|---|---|---|
| **0.00** | -1445.2 | 13.6 | 1.0 | 0.0 | 0.0 | -0.0 |
| **11.00** | -1398.6 | 13.6 | 1.0 | 0.0 | 11.2 | -149.6 |
| **22.00** | -1351.9 | 13.6 | 1.0 | 0.0 | 22.4 | -299.1 |
| **33.00** | -1305.3 | 13.6 | 1.0 | 0.0 | 33.6 | -448.7 |
| **44.00** | **-1258.6** | 13.6 | 1.0 | 0.0 | 44.8 | -598.3 |

**Bent 2, Column 2**

| Location<br>ft | AX<br>kip | VY<br>kip | VZ<br>kip | TX<br>kip·ft | MY<br>kip·ft | MZ<br>kip·ft |
|---|---|---|---|---|---|---|
| **0.00** | -1448.8 | 13.4 | 1.0 | 0.0 | 0.0 | -0.0 |
| **11.00** | -1402.1 | 13.4 | 1.0 | 0.0 | 11.5 | -147.7 |
| **22.00** | -1355.5 | 13.4 | 1.0 | 0.0 | 23.0 | -295.4 |
| **33.00** | -1308.8 | 13.4 | 1.0 | 0.0 | 34.4 | -443.1 |
| **44.00** | **-1262.1** | 13.4 | 1.0 | 0.0 | 45.9 | -590.8 |

**Bent 3, Column 1**

| Location<br>ft | AX<br>kip | VY<br>kip | VZ<br>kip | TX<br>kip·ft | MY<br>kip·ft | MZ<br>kip·ft |
|---|---|---|---|---|---|---|
| **0.00** | -1403.6 | -13.9 | -0.0 | 0.0 | -0.0 | 0.0 |
| **11.75** | -1353.8 | -13.9 | -0.0 | 0.0 | -0.2 | 163.2 |
| **23.50** | -1303.9 | -13.9 | -0.0 | 0.0 | -0.4 | 326.4 |
| **35.25** | -1254.1 | -13.9 | -0.0 | 0.0 | -0.7 | 489.5 |
| **47.00** | **-1204.3** | -13.9 | -0.0 | 0.0 | -0.9 | 652.7 |

**Bent 3, Column 2**

| Location<br>ft | AX<br>kip | VY<br>kip | VZ<br>kip | TX<br>kip·ft | MY<br>kip·ft | MZ<br>kip·ft |
|---|---|---|---|---|---|---|
| **0.00** | -1427.3 | -13.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| **11.75** | -1377.5 | -13.9 | 0.0 | 0.0 | 0.0 | 163.1 |
| **23.50** | -1327.6 | -13.9 | 0.0 | 0.0 | 0.1 | 326.2 |
| **35.25** | -1277.8 | -13.9 | 0.0 | 0.0 | 0.1 | 489.3 |
| **47.00** | **-1228.0** | -13.9 | 0.0 | 0.0 | 0.1 | 652.4 |

## Dead Load - Unfactored Bent Reactions

| Bent Location | AX<br>kip | VY<br>kip | VZ<br>kip | TX<br>kip·ft | MY<br>kip·ft | MZ<br>kip·ft |
|---|---|---|---|---|---|---|
| Bent 2 Col Bots | -2894.0 | 27.0 | 2.1 | 0.0 | 0.0 | -0.0 |
| Bent 2 Col Tops | -2520.8 | 27.0 | 2.1 | 0.0 | 90.7 | -1189.0 |
| Bent 3 Col Bots | -2830.9 | -27.8 | -0.0 | 0.0 | -0.0 | 0.0 |
| Bent 3 Col Tops | -2432.2 | -27.8 | -0.0 | 0.0 | -0.8 | 1305.1 |

## Additional Dead Load - Unfactored Forces - Columns

**Bent 2, Column 1**

| Location | AX | VY | VZ | TX | MY | MZ |
|---|---|---|---|---|---|---|
| ft | kip | kip | kip | kip·ft | kip·ft | kip·ft |
| 0.00 | -230.6 | 2.4 | 0.2 | 0.0 | 0.0 | -0.0 |
| 11.00 | -230.6 | 2.4 | 0.2 | 0.0 | 2.1 | -26.8 |
| 22.00 | -230.6 | 2.4 | 0.2 | 0.0 | 4.3 | -53.7 |
| 33.00 | -230.6 | 2.4 | 0.2 | 0.0 | 6.4 | -80.5 |
| 44.00 | **-230.6** | 2.4 | 0.2 | 0.0 | 8.5 | -107.3 |

**Bent 2, Column 2**

| Location | AX | VY | VZ | TX | MY | MZ |
|---|---|---|---|---|---|---|
| ft | kip | kip | kip | kip·ft | kip·ft | kip·ft |
| 0.00 | -231.3 | 2.4 | 0.2 | 0.0 | 0.0 | -0.0 |
| 11.00 | -231.3 | 2.4 | 0.2 | 0.0 | 2.2 | -26.5 |
| 22.00 | -231.3 | 2.4 | 0.2 | 0.0 | 4.4 | -53.0 |
| 33.00 | -231.3 | 2.4 | 0.2 | 0.0 | 6.6 | -79.5 |
| 44.00 | **-231.3** | 2.4 | 0.2 | 0.0 | 8.7 | -106.0 |

**Bent 3, Column 1**

| Location | AX | VY | VZ | TX | MY | MZ |
|---|---|---|---|---|---|---|
| ft | kip | kip | kip | kip·ft | kip·ft | kip·ft |
| 0.00 | -221.0 | -2.5 | -0.0 | 0.0 | -0.0 | 0.0 |
| 11.75 | -221.0 | -2.5 | -0.0 | 0.0 | -0.2 | 29.3 |
| 23.50 | -221.0 | -2.5 | -0.0 | 0.0 | -0.3 | 58.6 |
| 35.25 | -221.0 | -2.5 | -0.0 | 0.0 | -0.5 | 87.9 |
| 47.00 | **-221.0** | -2.5 | -0.0 | 0.0 | -0.6 | 117.1 |

**Bent 3, Column 2**

| Location | AX | VY | VZ | TX | MY | MZ |
|---|---|---|---|---|---|---|
| ft | kip | kip | kip | kip·ft | kip·ft | kip·ft |
| 0.00 | -225.2 | -2.5 | -0.0 | 0.0 | -0.0 | 0.0 |
| 11.75 | -225.2 | -2.5 | -0.0 | 0.0 | -0.1 | 29.3 |
| 23.50 | -225.2 | -2.5 | -0.0 | 0.0 | -0.2 | 58.5 |
| 35.25 | -225.2 | -2.5 | -0.0 | 0.0 | -0.3 | 87.8 |
| 47.00 | **-225.2** | -2.5 | -0.0 | 0.0 | -0.5 | 117.1 |

## Additional Dead Load - Unfactored Bent Reactions

| Bent Location | AX | VY | VZ | TX | MY | MZ |
|---|---|---|---|---|---|---|
| | kip | kip | kip | kip·ft | kip·ft | kip·ft |
| Bent 2 Col Bots | -461.9 | 4.8 | 0.4 | 0.0 | 0.0 | -0.0 |
| Bent 2 Col Tops | -461.9 | 4.8 | 0.4 | 0.0 | 17.3 | -213.4 |
| Bent 3 Col Bots | -446.2 | -5.0 | -0.0 | 0.0 | -0.0 | 0.0 |
| Bent 3 Col Tops | -446.2 | -5.0 | -0.0 | 0.0 | -1.1 | 234.2 |

# APPENDIX – C

(Input file for xSECTION)

```
xSECTION
VER._2.40,_MAR-14-99
LICENSE (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY (choices: GOVERNMENT/CONSULTANT)
Government
NAME_OF_FIRM
Caltrans
BRIDGE_NAME
EXAMPLE BRIDGE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY
***********************************************************
*                    6' Dia. Column                       *
*                                                         *
*                                   4/17/06               *
***********************************************************
Subsection definition is supported by coordinates
bending parallel to x-axis (horiz.)
local x- and y- axes parallel to global X- and YUnits
are Kips and inches
**************************************************************
* Welded hoops or seismic hooks are required for confinement *
* to be effective.
                                    *
**************************************************************
CONC_TYPES_START
NUMBER_OF_TYPES 2
TYPE_NUMBER 1 MODEL mander
   CONFINED_SUBSECTION_SHAPE circular
       CONFINED_SUBSECTION_DIAM 68.00
                      CONF_TYPE hoops
CONF_STEEL_TYPE 1 CONF_BAR_AREA 0.79 CONF_BAR_DIAM 1.00
                 CONF_BAR_SPACING 5.0
 MAIN_BAR_TOTAL 26 MAIN_BAR_AREA 2.25
    STRAIN_e0 0.002 STRAIN_eu 0.005 ULT_STRAIN_FACT 1.0
    STRESS_f0 5.28 STRESS_fu 2.64
    UNIT_WEIGHT_FACT 0.986
TYPE_NUMBER 2 MODEL unconfined_mander
    STRAIN_e0 0.002 STRAIN_eu 0.005 ULT_STRAIN_FACT 1.0
    STRESS_f0 5.28 STRESS_fu 2.64
    UNIT_WEIGHT_FACT 0.986
CONC_TYPES_END
***************************************************************
* A706 Steel type 2 is for #11 and larger bars. Type 1 is for *
* smaller bars.                                               *
***************************************************************
STEEL_TYPES_START
NUMBER_OF_TYPES 2
TYPE_NUMBER 1 MODEL park
YIELD_STRAIN 0.0023 HARDEN_STRAIN 0.0150 ULT_STRAIN 0.09
YIELD_STRESS 68.0 ULT_STRESS 95.0
MODULUS 29000.0
TYPE_NUMBER 2 MODEL park
YIELD_STRAIN 0.0023 HARDEN_STRAIN 0.0075 ULT_STRAIN 0.06
YIELD_STRESS 68.0 ULT_STRESS 95.0
MODULUS 29000.0
STEEL_TYPES_END
*************************************************
* Comment area                                  *
* Arc_strip is used to model a full circle.     *
*************************************************
SUBSECTION_START
NUMBER_OF_SUBSECTIONS 2
SUBSECTION_NUMBER 1
```

```
    SHAPE arc_strip
    CENTER_GLOBAL_X_Y 0 0 START_ANGLE 0 DURATION_CCW
    RADIUS_OUTER 34.00 RADIUS_INNER 0
    NUMBER_OF_FIBERS_RADIAL 10 NUMBER_OF_FIBERS_ANGULAR 40
    CONC_TYPE 1
    MIRROR_4_WAYS no
SUBSECTION_NUMBER 2
    SHAPE arc_strip
    CENTER_GLOBAL_X_Y 0 0 START_ANGLE 0 DURATION_CCW 360
    RADIUS_OUTER 36.00 RADIUS_INNER 34.00
    NUMBER_OF_FIBERS_RADIAL 1 NUMBER_OF_FIBERS_ANGULAR 50
    CONC_TYPE 2
    MIRROR_4_WAYS no
SUBSECTION_END
*********************************************************
* Comment area                                          *
* Circular rebar distribution is a special case of arc  *
* distribution                                          *
*********************************************************
REBAR_LAYOUT_START
NUMBER_OF_REBAR_GROUPS 1
GROUP_NUMBER 1
    LAYOUT_SHAPE circular
    NUMBER_OF_REBARS 26 AREA_OF_EACH_BAR 2.25 STEEL_TYPE 2
    CENTER_GLOBAL_X_Y 0 0 START_ANGLE 0 DURATION_CCW 360
    RADIUS 31.930
    MIRROR_4_WAYS no
REBAR_LAYOUT_END
********************************************************
AXIAL_LOAD
    LOAD_VALUE 1694
    CENTER_OF_LOAD_APPLICATION_GLOBAL_X_Y 0 0
***************************************************************
* Comment area                                                *
* Let the cover concrete fail but stop at first longitudinal  *
* rebar failure.To control the initial guess of the Neutral   *
* Axis a factor is defined which varies from 0.01 to 0.99     *
* as shown below. This is used if there is instablity in      *
* the moment-curvature curve.                                 *
***************************************************************
ANALYSIS_CONTROL
    STOP_DUE_FIRST_CONC_FAILURE no
    STOP_DUE_FIRST_REBAR_FAILURE yes
    BENDING_AXIS_CCW_ROTATION_DEGREES 0
    NEUTRAL_AXIS_PROXIMITY_TO_COMPRESSION_EDGE 0.99
    CONVERGENCE_TOLERANCE 0.001
*********************************************************
RESULTS_REQUESTED
    MOMENT_AT_GLOBAL_X_Y 0 0
    CONC_FIBER_INFO_OUTPUT no
    REBAR_FIBER_INFO_OUTPUT yes
*********************************************************
```

## APPENDIX – D

(Output from xSECTION)

```
04/17/2006, 11:45
***********************************************************
*                                                         *
*                       xSECTION                          *
*                                                         *
*               DUCTILITY and STRENGTH of                 *
*      Circular, Semi-Circular, full and partial Rings,   *
*   Rectangular, T-, I-, Hammer head, Octagonal, Polygons *
*       or any combination of above shapes forming        *
*          Concrete Sections using Fiber Models           *
*                                                         *
* VER._2.40,_MAR-14-99                                    *
*                                                         *
* Copyright (C) 1994, 1995, 1999 By Mark Seyed Mahan.     *
*                                                         *
* A proper license must be obtained to use this software. *
* For GOVERNMENT work call 916-227-8404, otherwise leave a *
* message at 530-756-2367. The author makes no expressed or*
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for         *
* incidental or consequential damages arising out of the  *
* use of this program.                                    *
*                                                         *
***********************************************************
This output was generated by running:
xSECTION
VER._2.40,_MAR-14-99
LICENSE    (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY     (choices: GOVERNMENT/CONSULTANT)
Government
NAME_OF_FIRM
Caltrans
BRIDGE_NAME
EXAMPLE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY
```

Concrete Type Information:

| | ----------strains-------- | | | | --------strength-------- | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | e0 | e2 | ecc | eu | f0 | f2 | fcc | fu | E | W |
| 1 | 0.0020 | 0.0040 | 0.0055 | 0.0145 | 5.28 | 6.98 | 7.15 | 6.11 | 4313 | 148 |
| 2 | 0.0020 | 0.0040 | 0.0020 | 0.0050 | 5.28 | 3.61 | 5.28 | 2.64 | 4313 | 148 |

Steel Type Information:

| | -----strains------ | | | --strength- | | |
|---|---|---|---|---|---|---|
| Type | ey | eh | eu | fy | fu | E |
| 1 | 0.0023 | 0.0150 | 0.0900 | 68.00 | 95.00 | 29000 |
| 2 | 0.0023 | 0.0075 | 0.0600 | 68.00 | 95.00 | 29000 |

Steel Fiber Information:

| Fiber No. | type | xc in | yc in | area in^2 |
|---|---|---|---|---|
| 1 | 2 | 31.93 | 0.00 | 2.25 |
| 2 | 2 | 31.00 | 7.64 | 2.25 |
| 3 | 2 | 28.27 | 14.84 | 2.25 |
| 4 | 2 | 23.90 | 21.17 | 2.25 |
| 5 | 2 | 18.14 | 26.28 | 2.25 |
| 6 | 2 | 11.32 | 29.86 | 2.25 |

| | | | | |
|---|---|---|---|---|
| 7 | 2 | 3.85 | 31.70 | 2.25 |
| 8 | 2 | -3.85 | 31.70 | 2.25 |
| 9 | 2 | -11.32 | 29.86 | 2.25 |
| 10 | 2 | -18.14 | 26.28 | 2.25 |
| 11 | 2 | -23.90 | 21.17 | 2.25 |
| 12 | 2 | -28.27 | 14.84 | 2.25 |
| 13 | 2 | -31.00 | 7.64 | 2.25 |
| 14 | 2 | -31.93 | 0.00 | 2.25 |
| 15 | 2 | -31.00 | -7.64 | 2.25 |
| 16 | 2 | -28.27 | -14.84 | 2.25 |
| 17 | 2 | -23.90 | -21.17 | 2.25 |
| 18 | 2 | -18.14 | -26.28 | 2.25 |
| 19 | 2 | -11.32 | -29.86 | 2.25 |
| 20 | 2 | -3.85 | -31.70 | 2.25 |
| 21 | 2 | 3.85 | -31.70 | 2.25 |
| 22 | 2 | 11.32 | -29.85 | 2.25 |
| 23 | 2 | 18.14 | -26.28 | 2.25 |
| 24 | 2 | 23.90 | -21.17 | 2.25 |
| 25 | 2 | 28.27 | -14.84 | 2.25 |
| 26 | 2 | 31.00 | -7.64 | 2.25 |

Force Equilibrium Condition of the x-section:

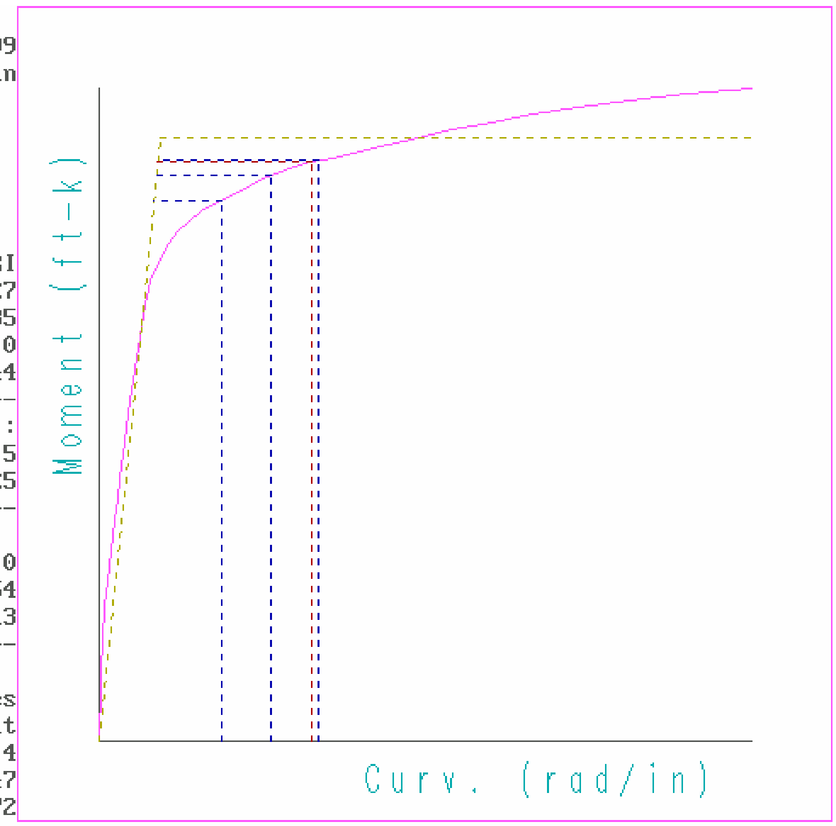
| step | Max. Conc. Strain epscmax | Neutral Axis in. | Max. Steel Strain Tens. | Conc. Comp. | Steel force Comp. | Steel force Tens. | P/S force | Net force | Curvature rad/in | Moment (K-ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00000 | 0.00 | 0.0000 | 0 | 0 | 0 | 0 | 0.00 | 0.000000 | 0 |
| 1 | 0.00029 | -12.30 | -0.0001 | 1570 | 174 | -49 | 0 | 1.52 | 0.000006 | 2588 |
| 2 | 0.00032 | -9.09 | -0.0002 | 1585 | 182 | -73 | 0 | 0.95 | 0.000007 | 2843 |
| 3 | 0.00035 | -6.26 | -0.0002 | 1606 | 192 | -103 | 0 | 1.16 | 0.000008 | 3106 |
| 4 | 0.00039 | -3.74 | -0.0003 | 1631 | 203 | -140 | 0 | -0.03 | 0.000010 | 3381 |
| 5 | 0.00043 | -1.52 | -0.0003 | 1664 | 214 | -184 | 0 | -0.31 | 0.000012 | 3674 |
| 6 | 0.00048 | 0.46 | -0.0004 | 1704 | 226 | -237 | 0 | -0.37 | 0.000013 | 3987 |
| 7 | 0.00053 | 2.14 | -0.0005 | 1752 | 242 | -299 | 0 | 0.90 | 0.000016 | 4329 |
| 8 | 0.00059 | 3.71 | -0.0006 | 1810 | 259 | -373 | 0 | 1.37 | 0.000018 | 4700 |
| 9 | 0.00065 | 5.09 | -0.0008 | 1874 | 276 | -457 | 0 | -0.31 | 0.000021 | 5106 |
| 10 | 0.00072 | 6.27 | -0.0009 | 1950 | 295 | -551 | 0 | 0.11 | 0.000024 | 5551 |
| 11 | 0.00079 | 7.28 | -0.0011 | 2035 | 316 | -656 | 0 | 0.47 | 0.000028 | 6039 |
| 12 | 0.00087 | 8.20 | -0.0013 | 2131 | 340 | -778 | 0 | -1.00 | 0.000031 | 6575 |
| 13 | 0.00097 | 9.02 | -0.0015 | 2241 | 368 | -917 | 0 | -1.40 | 0.000036 | 7164 |
| 14 | 0.00107 | 9.71 | -0.0017 | 2363 | 400 | -1070 | 0 | -0.52 | 0.000041 | 7806 |
| 15 | 0.00118 | 10.29 | -0.0019 | 2497 | 434 | -1237 | 0 | -0.19 | 0.000046 | 8505 |
| 16 | 0.00131 | 10.78 | -0.0022 | 2641 | 473 | -1421 | 0 | -0.89 | 0.000052 | 9262 |
| 17 | 0.00144 | 11.29 | -0.0025 | 2784 | 514 | -1604 | 0 | 0.07 | 0.000058 | 9998 |
| 18 | 0.00160 | 11.99 | -0.0029 | 2891 | 555 | -1751 | 0 | 0.67 | 0.000067 | 10544 |
| 19 | 0.00176 | 12.76 | -0.0034 | 2976 | 595 | -1877 | 0 | 0.26 | 0.000076 | 10983 |
| 20 | 0.00195 | 13.51 | -0.0039 | 3046 | 638 | -1989 | 0 | 0.55 | 0.000087 | 11360 |
| 21 | 0.00216 | 14.31 | -0.0046 | 3101 | 679 | -2087 | 0 | -0.94 | 0.000099 | 11663 |
| 22 | 0.00238 | 15.06 | -0.0053 | 3141 | 725 | -2174 | 0 | -1.42 | 0.000114 | 11921 |
| 23 | 0.00264 | 15.79 | -0.0062 | 3171 | 781 | -2260 | 0 | -1.53 | 0.000130 | 12138 |
| 24 | 0.00291 | 16.44 | -0.0072 | 3195 | 841 | -2344 | 0 | -1.23 | 0.000149 | 12341 |
| 25 | 0.00322 | 16.99 | -0.0083 | 3210 | 889 | -2406 | 0 | -0.96 | 0.000170 | 12508 |
| 26 | 0.00356 | 17.39 | -0.0094 | 3249 | 929 | -2483 | 0 | 0.66 | 0.000192 | 12718 |
| 27 | 0.00394 | 17.67 | -0.0106 | 3309 | 952 | -2568 | 0 | -1.69 | 0.000215 | 12926 |
| 28 | 0.00435 | 17.91 | -0.0119 | 3361 | 978 | -2646 | 0 | -1.26 | 0.000241 | 13129 |
| 29 | 0.00481 | 18.07 | -0.0134 | 3388 | 1008 | -2703 | 0 | -0.57 | 0.000269 | 13267 |
| 30 | 0.00532 | 18.11 | -0.0148 | 3413 | 1037 | -2756 | 0 | 0.59 | 0.000298 | 13362 |
| 31 | 0.00588 | 18.15 | -0.0164 | 3461 | 1048 | -2816 | 0 | -0.56 | 0.000330 | 13495 |
| 32 | 0.00650 | 18.21 | -0.0183 | 3515 | 1060 | -2881 | 0 | -0.42 | 0.000366 | 13660 |
| 33 | 0.00718 | 18.27 | -0.0203 | 3570 | 1072 | -2948 | 0 | -0.93 | 0.000406 | 13834 |
| 34 | 0.00794 | 18.30 | -0.0225 | 3630 | 1087 | -3021 | 0 | 1.38 | 0.000449 | 14017 |
| 35 | 0.00878 | 18.33 | -0.0249 | 3686 | 1103 | -3096 | 0 | -1.20 | 0.000497 | 14194 |
| 36 | 0.00971 | 18.34 | -0.0275 | 3743 | 1122 | -3171 | 0 | -0.61 | 0.000550 | 14368 |
| 37 | 0.01073 | 18.34 | -0.0304 | 3792 | 1148 | -3246 | 0 | 0.07 | 0.000608 | 14536 |
| 38 | 0.01186 | 18.34 | -0.0336 | 3834 | 1181 | -3321 | 0 | -0.67 | 0.000672 | 14695 |

```
39   0.01312   18.38 -0.0373  3847  1217 -3371     0     -0.48 0.000745   14841
40   0.01450   18.41 -0.0414  3857  1256 -3420     0     -1.66 0.000825   14976


First Yield of Rebar Information (not Idealized):

     Rebar Number 20
     Coordinates X and Y (global in.)  -3.85, -31.70
     Yield strain =  0.00230
     Curvature (rad/in)=  0.000054
     Moment (ft-k) =    9537


Cross Section Information:

     Axial Load on Section (kips) =  1694
     Percentage of Main steel in Cross Section =   1.44
     Concrete modulus used in Idealization (ksi) =  4313
     Cracked Moment of Inertia (ft^4) =    23.717


Idealization of Moment-Curvature Curve by Various Methods:


                  Points on Curve       Idealized Values
                  ===============   =============================
Method     Conc.                    Yield         symbol  Plastic
 ID      | Strain  Curv.   Moment | Curv.  Moment   for   Curv.
         | in/in   rad/in  (K-ft) | rad/in (K-ft)  moment rad/in
Strain @ 0.003   0.000155   12388 0.000070   12388   Mn  0.000755
Strain @ 0.004   0.000219   12957 0.000073   12957   Mn  0.000752
Strain @ 0.005   0.000279   13302 0.000075   13302   Mn  0.000750
CALTRANS 0.00720 0.000407   13838 0.000078   13838   Mp  0.000747
UCSD@5phy0.00483 0.000270   13271 0.000075   13271   Mn  0.000750
```

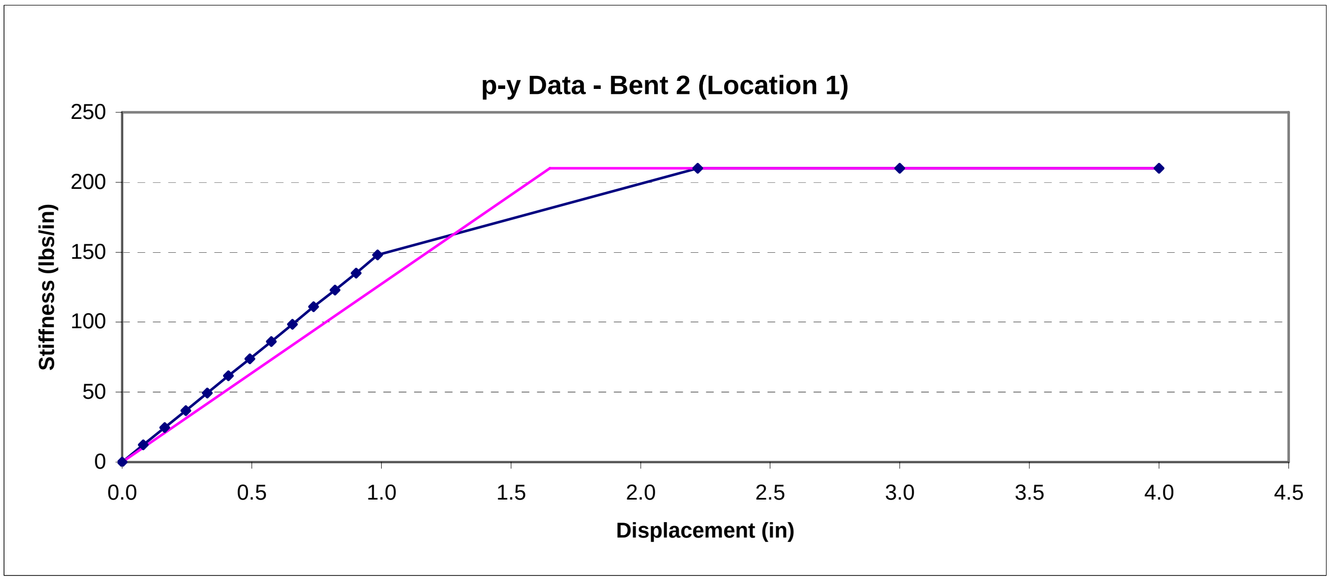
# APPENDIX – E

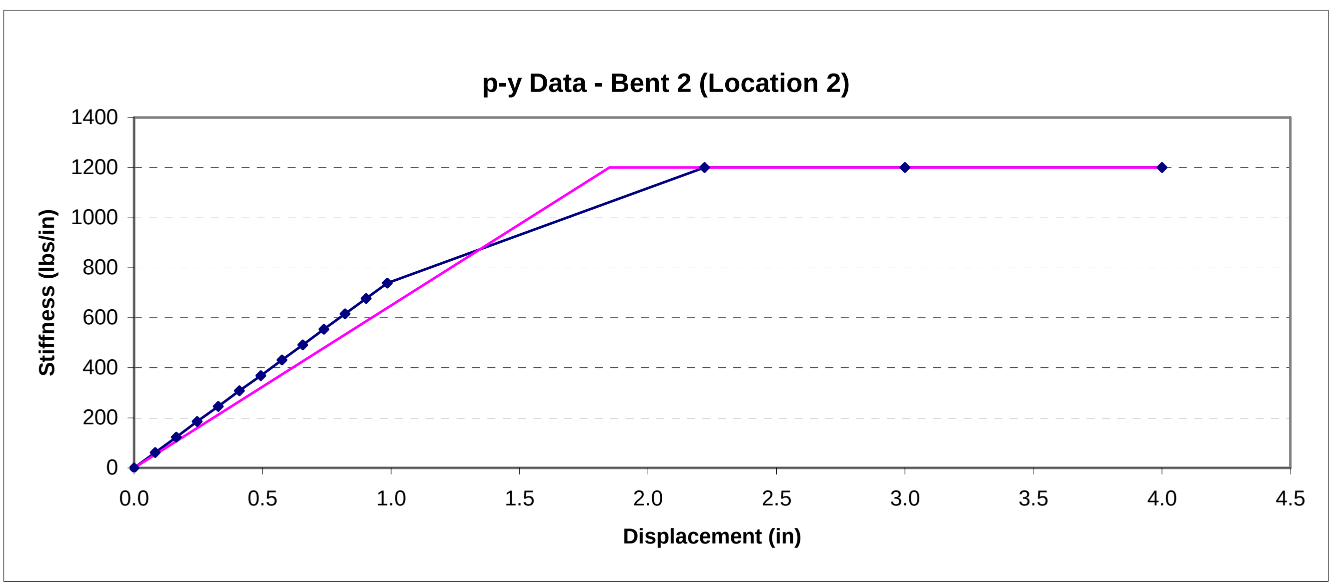
(Moment – Curvature Relationship)

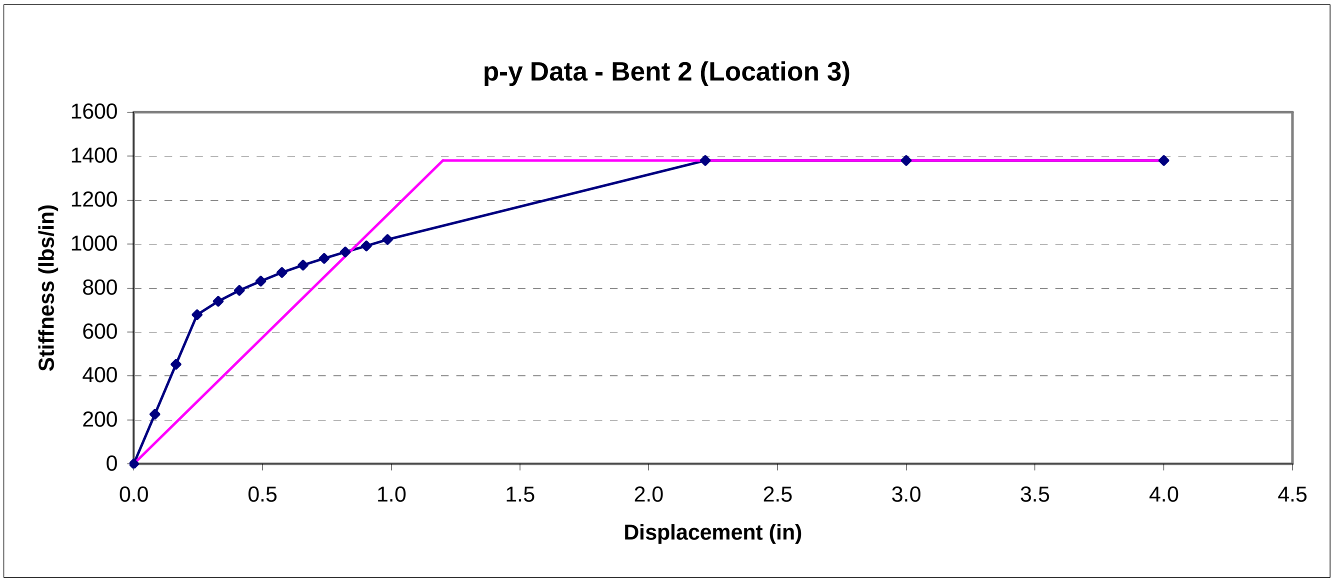
```
xSECTION
VER._2.40,_MAR-14-99
(C)'99 Mark S. Mahan
Licensed to:
Caltrans
EXAMPLE
99-9999
05/18/2006, 14:03
File: b2dlx.xse
PROTYPE BRIDGE - BRI
Area_G(ft^2)=  28.27
I_G(ft^4)=     63.35
Axial (kips)= 1694.0
Percent steel=  1.44
--------------------
Moment-Curv. Curve :
Mmax ft-k=   14975.5
phi_max    = 0.000825
--------------------
Rebar Yield info:
My (k-ft)=    9537.0
phi_y      = 0.000054
Ec    (ksi)=    4313
--------------------
Idealized values:
(CT) dark blue lines
others see print-out
Mp (k-ft)=   13838.4
phi_p      = 0.000747
Icr(ft^4)=     23.72
```

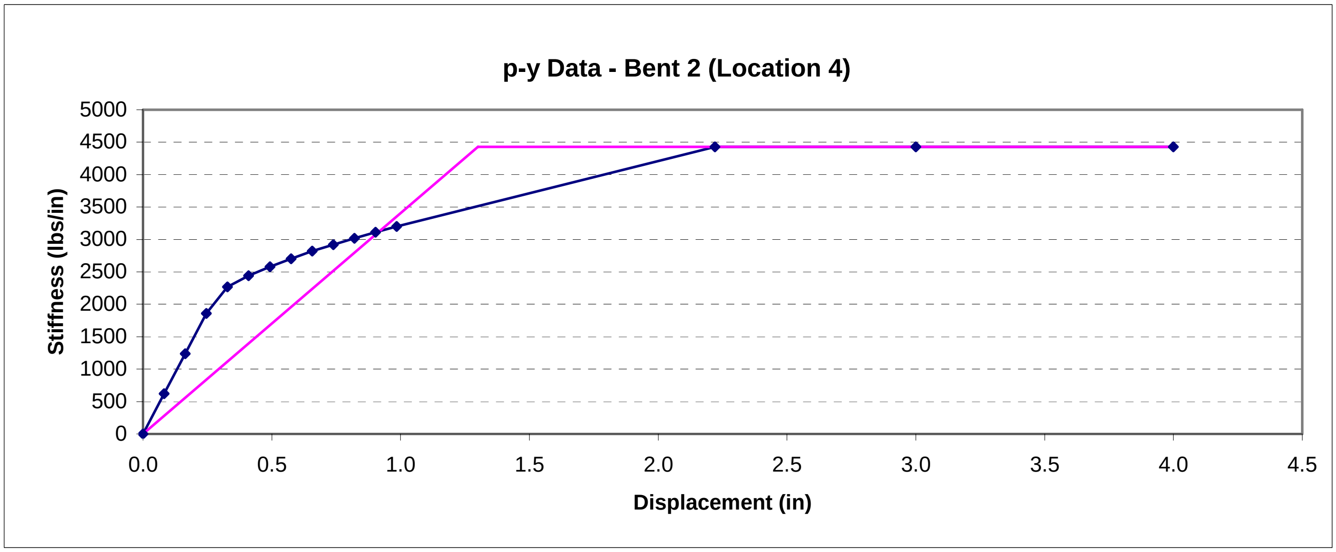


**APPENDIX - F**
(Soil Spring Data)



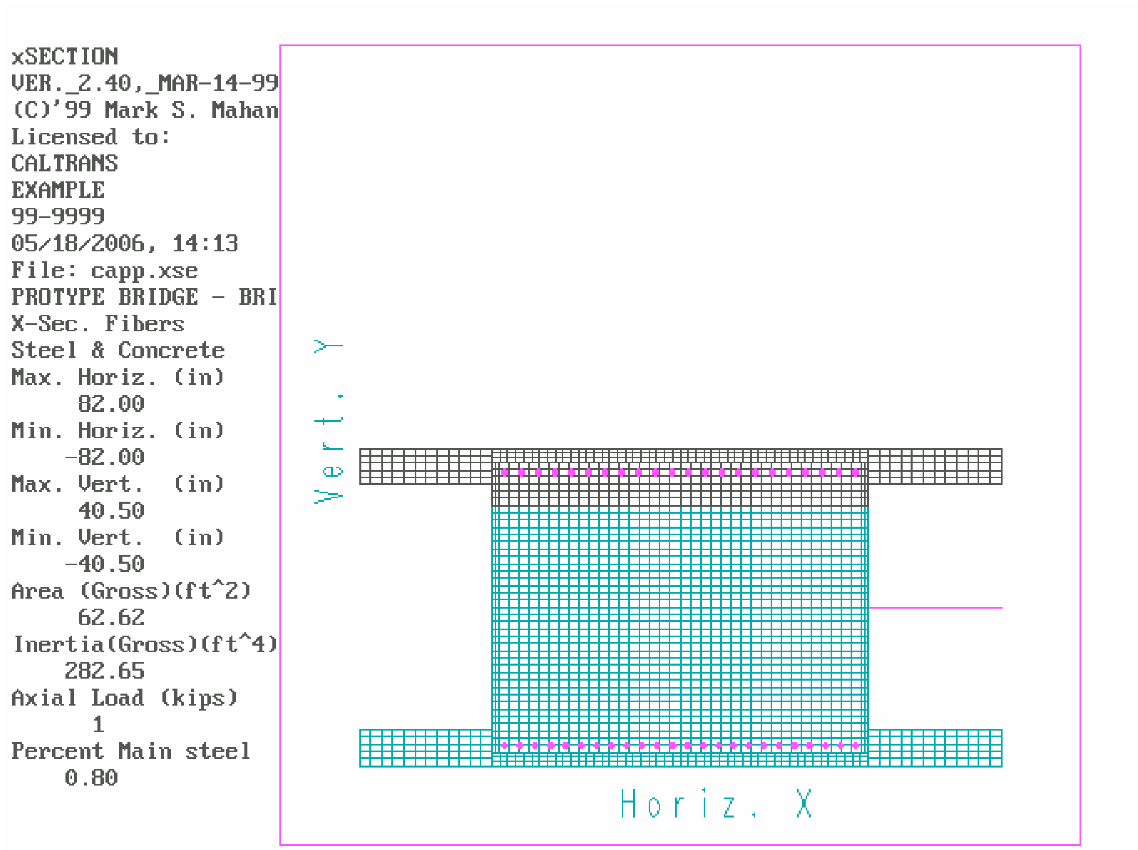




p-y Data - Bent 2 (Location 3)
Stiffness (lbs/in)
1600
1400
1200
1000
800
600
400
200
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Displacement (in)


p-y Data - Bent 2 (Location 4)
Stiffness (lbs/in)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Displacement (in)

# APPENDIX – G

(Bent Cap – xSECTION Model)



# APPENDIX – H1

(Bent Cap – Positive Bending Section Capacities)

```
05/16/2006, 10:17
*************************************************************
*                                                           *
*                       xSECTION                            *
*                                                           *
*               DUCTILITY and STRENGTH of                   *
*     Circular, Semi-Circular, full and partial Rings,      *
*  Rectangular, T-, I-, Hammer head, Octagonal, Polygons    *
*      or any combination of above shapes forming           *
*         Concrete Sections using Fiber Models              *
*                                                           *
* VER._2.40,_MAR-14-99                                      *
*                                                           *
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* In no event shall the author be held liable for           *
* incidental or consequential damages arising out of the    *
* use of this program.                                      *
*                                                           *
*************************************************************
This output was generated by running:
xSECTION
VER._2.40,_MAR-14-99
LICENSE    (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY     (choices: GOVERNMENT/CONSULTANT)
GOVERNMENT
NAME_OF_FIRM
CALTRANS
BRIDGE_NAME
EXAMPLE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY



Concrete Type Information:

     ----------strains--------  --------strength--------
Type   e0    e2    ecc     eu     f0    f2    fcc    fu    E    W
 1 0.0020 0.0040 0.0027 0.0115  5.00  5.01  5.35  2.63  4200   148
 2 0.0020 0.0040 0.0020 0.0050  5.00  3.52  5.00  2.50  4200   148


Steel Type Information:

     -----strains------  --strength-
Type  ey     eh     eu    fy    fu    E
 1 0.0023 0.0150 0.0900 68.00 95.00 29000
 2 0.0023 0.0075 0.0600 68.00 95.00 29000
```

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

..........................................................................................................................

```
First Yield of Rebar Information (not Idealized):

     Rebar Number 1
```

```
     Coordinates X and Y (global in.) -44.80, -35.49
     Yield strain =  0.00230
     Curvature (rad/in)=  0.000037
     Moment (ft-k) =   14873


Cross Section Information:

     Axial Load on Section (kips) =     1
     Percentage of Main steel in Cross Section =   0.80
     Concrete modulus used in Idealization (ksi) =  4200
     Cracked Moment of Inertia (ft^4) =    55.568


Idealization of Moment-Curvature Curve by Various Methods:


                  Points on Curve        Idealized Values
                  ===============   =============================
Method     Conc.                    Yield         symbol  Plastic
 ID      | Strain  Curv.   Moment | Curv.  Moment   for   Curv.
         | in/in   rad/in  (K-ft) | rad/in (K-ft)  moment rad/in
Strain @ 0.003   0.000520   21189 0.000053   21189   Mn  0.000665
Strain @ 0.004   0.000684   21635 0.000054   21635   Mn  0.000664
Strain @ 0.005   0.000000       0 0.000000       0   Mn  0.000718
CALTRANS 0.00187 0.000306   19484 0.000048   19484   Mp  0.000669
UCSD@5phy0.00126 0.000184   17426 0.000043   17426   Mn  0.000674
```

## APPENDIX – H2

(Bent Cap – Negative Bending Section Capacities)

```
05/15/2006, 08:26
************************************************************
*                                                          *
*                       xSECTION                           *
*                                                          *
*               DUCTILITY and STRENGTH of                  *
*      Circular, Semi-Circular, full and partial Rings,    *
*  Rectangular, T-, I-, Hammer head, Octagonal, Polygons   *
*       or any combination of above shapes forming         *
*          Concrete Sections using Fiber Models            *
*                                                          *
* VER._2.40,_MAR-14-99                                     *
*                                                          *
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* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for          *
* incidental or consequential damages arising out of the   *
* use of this program.                                     *
*                                                          *
************************************************************
This output was generated by running:
xSECTION
VER._2.40,_MAR-14-99
LICENSE    (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY     (choices: GOVERNMENT/CONSULTANT)
GOVERNMENT
NAME_OF_FIRM
CALTRANS
BRIDGE_NAME
EXAMPLE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY


Concrete Type Information:

     ----------strains--------  --------strength--------
Type   e0     e2    ecc     eu     f0    f2    fcc    fu    E    W
 1 0.0020 0.0040 0.0027 0.0115  5.00  5.01  5.35  2.63  4200   148
 2 0.0020 0.0040 0.0020 0.0050  5.00  3.52  5.00  2.50  4200   148


Steel Type Information:

     -----strains------  --strength-
Type  ey     eh     eu    fy    fu    E
 1 0.0023 0.0150 0.0900 68.00 95.00 29000
 2 0.0023 0.0075 0.0600 68.00 95.00 29000
```

..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................
..........................................................................................................................

```
First Yield of Rebar Information (not Idealized):

     Rebar Number 25
```

# APPENDIX – H2

(Bent Cap – Negative Bending Section Capacities) - Continues

```
     Coordinates X and Y (global in.)  44.80, -34.49
     Yield strain =  0.00230
     Curvature (rad/in)=  0.000037
     Moment (ft-k) =   13030


Cross Section Information:

     Axial Load on Section (kips) =     1
     Percentage of Main steel in Cross Section =   0.80
     Concrete modulus used in Idealization (ksi) =  4200
```

**Cracked Moment of Inertia (ft^4) =    48.938**

```
Idealization of Moment-Curvature Curve by Various Methods:


                  Points on Curve        Idealized Values
                  ===============   =============================
Method     Conc.                    Yield         symbol  Plastic
 ID      | Strain  Curv.   Moment | Curv.  Moment   for   Curv.
         | in/in   rad/in  (K-ft) | rad/in (K-ft)  moment rad/in
Strain @ 0.003   0.000593   19436 0.000055   19436   Mn  0.000563
Strain @ 0.004   0.000000       0 0.000000       0   Mn  0.000618
Strain @ 0.005   0.000000       0 0.000000       0   Mn  0.000618
CALTRANS 0.00159 0.000282   17307 0.000049   17307   Mp  0.000569
UCSD@5phy0.00117 0.000183   15735 0.000044   15735   Mn  0.000573
```

# APPENDIX – I

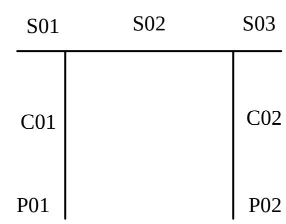
(wFRAME - Input File)

```
wFPREP
VER._1.12,_JAN-14-95
JOB_TITLE
Design Academy Example No: 1 (Bent 2)
*********************************************************************
* Columns are pinned at the base. Column longitudinal reinforcement *
* consists of 26, #14 bars. The lateral reinforcement consists of   *
* #8 Hoops at 5" spacing.                                           *
*                                                                   *
*                                         5/10/06                   *
*********************************************************************
All units in kips and feet
******************************************************************
            ***  Analysis Control Block Info ***

The following block of information is for analysis control.
Number of spans and number of link beams are specified.
Direction of push is specified (push to left is not checked yet).
2nd deck out-of-phase push is not checked yet.
******************************************************************
ANALYSIS_CONTROL
    NUMBER_OF_SPANS     3
    NUMBER_OF_LINK_BEAMS   0
    DIRECTION_OF_PUSH       right
    2ND_DECK_OUT_OF_PHASE   no
******************************************************************
            ***  Structural Data Block Info ***

The follwing block of information is for definition of spans, columns
and piles. A span/column/pile code and number (example S01) is specified;
followed by total number of elements in span/col/pile; followed by number
of different types of segments over which all elements are defined. The logic
of this version is such that info for S01, C01, P01, S02, C02 P02, etc...
is expected in the specified order. If a column is connected to a pile cap
and a pile group and the user does not wish to model the pile group, then
the portion of the column below ground (usually 2') must be modeled as a pile
and the tip of the 2' pile should be modeled as fixed in X and Y translation
and fixed, partially released (spring), or completely released for moment
for a column to footing connection of pin nature.51.84
For each segment input the following:
Number of elements per segment;
Fixity code (rn= no release, rs=release start, re=release end);
Length of each element (L);
Depth of element in direction of bending (not used in this version);
Area of cross section;
Modulus of elasticity (Ei);
Softened modulus (Ef, not used in this version);
Cracked moment of inertia(Icr);
Uniform dead load q (negative for superstructure elements, zero otherwise);
Positive plastic moment capacity (Mpp);
Negative plastic moment capacity (Mpn);
Tolerance for elasto-plastic transition (.02 recommended);
Element status = e for elastic, i for inactive.
#   F   L    D      A      Ei     Ef     I     q      Mp    Mn      T  status
****************************************************************************
STRUCTURAL_DATA
S01   2  2
1  rn   4.72 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
1  rn   3.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
C01   4  2
1  rn   3.38 6.00  28.27 629528  62953  47.44     0   27676  27676    0.02 e
3  rn  11.93 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
P01   4  2
3  rn   2.05 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
```

Bent cap +ve effective inertia



Column effective inertia and plastic moment capacity.

```
1  rn   2.05 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
S02   6  4
1  rn   3.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
2  rn   7.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
2  rn   7.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
1  rn   3.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
C02   4  2
1  rn   3.38 6.00  28.27 629528  62953  47.44     0   27676  27676    0.02 e
3  rn  11.93 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
P02   4  2
3  rn   2.05 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
1  rn   2.05 6.00  28.27 629528  62953  23.72     0   13838  13838    0.02 e
S03   2  2
1  rn   3.00 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
1  rn   4.72 6.75  62.62 629528  62953  52.25 -68.40  27676  27676    0.02 e
******************************************************************************
                ***  Link Beam or Second Deck Block Info ***
```

Superstructure and bent cap weight uniformly distributed over the entire bent cap

```
Link beam or second deck option may be placed at any span or any
elevation relative to the superstructure (down is negative).

For each link beam indicate beam number; total number of elements;
nmber of segments; left end elevation; right end elevation.

For each link beam segment input the following:

        see Structural Data Block Info.

Data Specific to this bridge: Link Beams are NOT being used.
#   F   L    D      A      Ei     Ef     I     q      Mp    Mn      T  status
*******************************************************************
LINK_BEAM_DATA
*******************************************************************

                ***  Soil p-y Block Info ***

This section contains the p-y information. First the number of p-y curves
is specified in the analysis (max 50). Then For each p-y curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), p1, y1, p2, y2.
Data Specific to this bridge:

There are two layers of sand.
The top layer is loose sand with layer thickness of 3'.
The bottom layer is medimum dense sand with layer thickness of 5'
Two p-y curves are used per layer.
******************************************************************
PYS
NUMBER_OF_PYS   4
PY_NO.  NO._OF_SEGMENTS     P1       Y1       P2        Y2
  1     2            2.520     0.142   2.520     1.000
  2     2           14.400     0.154  14.400     1.000
  3     2           15.840     0.104  15.840     1.000
  4     2           47.880     0.108  47.880     1.000
*******************************************************************

                ***  Soil t-z Block Info ***

This section contains the t-z information. First the number of t-z curves
is specified in the analysis (max 50). Then For each t-z curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), t1, z1, t2, z2.

t-z curves are usually specified for muti-pile situation.
```

```
Data Specific to this bridge:
*******************************************************************
TZS
NUMBER_OF_TZS   0
TZ_NO.  NO._OF_SEGMENTS     T1      Z1      T2      Z2
*******************************************************************

                *** Foundation Block Info for p-y application ***

These p-y values are used to attach horizontal springs to the pile
nodes for lateral response of the pile in the soil-structure interaction
study.

This section contains the foundation information for the p-y applications.
A foundation location is defined as pile locations defined in the structural
input. As discussed earlier the portion of a column below ground is called
a pile.

For each foundation location (i.e. pile or column 1, 2, etc.) indicate:
location number; and the number of p-y applications.

Each soil layer is considered one p-y application in this example.
A soil layer may be subdivided into several segments, each considered
one application. You need to input one new line per each count of
application. Provide as many new lines as the number of
p-y applications with the following info:
Start & end depth of soil layer or sub-layer (measured from top of pile).
Starting p-y number at top of layer. End p-y number at bottom of layer
where linear interpolation is used for the generation of the intermediate
springs.

A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME. Also the group reduction factors
typically used in soil-structure interaction problems for pile-groups may
be applied through this factor.

Data Specific to this bridge:

*******************************************************************
FOUNDATIONS_PY
   |   NO. OF      |         |       |           |         | FACTOR
LOC| SOIL-LAYERS/ |START    |END    |START-PY  |END-PY  |FOR # OF
NO.| PY APPLIC.   |DEPTH    |DEPTH |  NO.      |   NO.  |  PILE
1       2
                     0.00     3.28    1          2        1
                     3.28     8.20    3          4        1
2       2
                     0.00     3.28    1          2        1
                     3.28     8.20    3          4        1
*******************************************************************

                *** Foundation Block Info for t-z application ***

This section contains the foundation information for the t-z applications.
The general logic followed in this section is similar to the p-y
applications. These values are used to attach vertical springs to the pile
nodes for axial response of the pile in the soil-structure interaction
study.

For each foundation location (i.e. column 1, 2, etc.) indicate:
location number, and the number of t-z applications.
Each soil layer may be considered one t-z application or
a soil layer may be subdivided into several segments, each considered
one application. Provide as many new lines as the number of
t-z applications with the following info:
start & end depth of soil (measured from top of pile). Starting t-z number
at top of layer. End t-z number at bottom of layer where linear interpolation
is used for the generation of the intermediate springs.
```

```
A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME.

Data Specific to this bridge: None

******************************************************************
FOUNDATIONS_TZ
   |   NO. OF     |         |       |           |          | FACTOR
LOC| SOIL-LAYERS/ |START    |END    |START-TZ   |END-TZ    |FOR # OF
NO.| TZ APPLIC.   |DEPTH    |DEPTH  |  NO.      |   NO.    |  PILES
1       0
2       0
******************************************************************

        ***  Boundary node Block Info for spring application  ***

This section contains the boundary information where additional springs
may be attached to the extreme boundaries of the structure. The locations
are at the pile tips and at the abutments.

The boundary locations are identified according to the structural definition
listed earlier in the input file. The following possibilities exist:

For transverse analysis of say a 2 column bent (pin at base of columns) on
pile group the following assumptions may be made if the user does not wish
to model the piles explicitly. The pile group at each footing location may
be modeled as providing fixity or spring action in horizontal direction (the
user must estimate the spring value, otherwise fixity must be used).
Therefore, boundary locations 0 and 3 are the overhangs and they must be
released in all components (rx, ry, rz). The locations 1 and 2 will be modeld
at column to footing connection as fx, fy, rz. In general for the transverse
analysis of bents with "n" columns, locationns 1 and n+1 indicate the ends
of cap beam and it usually is free (rx, ry, rz).


For the transverse analysis of the above bent the user may decide to model
the entire pile groups at the two foundations. The piles must be numbered as
seen on the elevation view of the bent. This example will be presented later
due to the complexity of the situation.

For the longitudinal analysis of a 2 span bridge one may input two ficticious
column/pile combinations at the abutments with proper releases to model the
roller action of the seat abutment support. In this case release the top of
the ficticious column for moment (rs in the element) and model the bottom
with fx, fy, rz. This column will not carry a shear in the longitudinal push
and it will only carry the dead load at the abutment. Attach a spring at the
right abutment to model the passive resistance of the soil (sx plus a new
line with k1, del1, k2, del2).

For Location: enter 0 for left end of frame, 1 to xx for tips of piles,
and the last location is for right end of frame.
After boundary location number enter the following info on the next line:
Fixity code for each X, Y and Z directions on consecutive lines:
(rx=release x dir., fx=fix x dir., sx=spring code in x dir. etc.).
If a spring is defined, the next line must be included for the spring
with the following info.:
Number of segments, stiffness and displacements
at breakpoints of the multi-linear curve ((ki,deli) for i=1, 2...)
(Input only 2 segments for this version with the plateaue segment
generated by computer as the third segment).
End bearing at tip of compression piles may be modeled with these springs.

Data Specific to this bridge:

For this simple example only fixity in the Y-direction is provided because
the t-z(s) were not explicitly modeled. With t-z modeling the structure will
be floating is soil with releases at all boundary locations to represent the
```

```
real condition.

******************************************************************
BOUNDARIES
LOCATION    FIXITY_CODE   NO._OF_SEGMENTS       ki       del1     k2    del2
    0
                rx
                ry
                rz
    1
                fx
                fy
                rz
    2
                fx
                fy
                rz
    3
                rx
                ry
                rz
******************************************************************
```

# APPENDIX – J

(*wFRAME* Output File)

```
05/15/2006, 07:47
Design Academy Example No: 1 (Bent 2)

**********************************************************
*                                                        *
*                      wFRAME                            *
*                                                        *
*          PUSH ANALYSIS of BRIDGE BENTS and FRAMES.     *
*                                                        *
*       Indicates formation of successive plastic hinges. *
*                                                        *
* VER._1.12,_JAN-14-95                                   *
*                                                        *
* Copyright (C) 1994 By Mark Seyed.                      *
*                                                        *
* This program should not be distributed under any       *
* condition. This release is for demo ONLY (beta testing *
* is not complete). The author makes no expressed or     *
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for        *
* incidental or consequential damages arising out of the *
* use of this program.                                   *
*                                                        *
**********************************************************


Node Point Information:

Fixity condition definitions:
    s=spring and value
    r=complete release
    f=complete fixity with imposed displacement

node    name    coordinates    -----------fixity --------
  #              X       Y     X-dir.     Y-dir.   Rotation
    1 S01.00     0.00     0.00   r          r          r
    2 S01.01     4.72     0.00   r          r          r
    3 S01.02     7.72     0.00   r          r          r
    4 C01.01     7.72    -3.38   r          r          r
    5 C01.02     7.72   -15.31   r          r          r
    6 C01.03     7.72   -27.24   r          r          r
    7 C01.04     7.72   -39.17   r          r          r
    8 P01.01     7.72   -41.22   s 1.4e+002  r          r
    9 P01.02     7.72   -43.27   s 4.1e+002  r          r
   10 P01.03     7.72   -45.32   s 6.7e+002  r          r
   11 P01.04     7.72   -47.37   f 0.0000   f 0.0000   r
   12 S02.01    10.72     0.00   r          r          r
   13 S02.02    17.72     0.00   r          r          r
   14 S02.03    24.72     0.00   r          r          r
   15 S02.04    31.72     0.00   r          r          r
   16 S02.05    38.72     0.00   r          r          r
   17 S02.06    41.72     0.00   r          r          r
   18 C02.01    41.72    -3.38   r          r          r
   19 C02.02    41.72   -15.31   r          r          r
   20 C02.03    41.72   -27.24   r          r          r
   21 C02.04    41.72   -39.17   r          r          r
   22 P02.01    41.72   -41.22   s 1.4e+002  r          r
   23 P02.02    41.72   -43.27   s 4.1e+002  r          r
   24 P02.03    41.72   -45.32   s 6.7e+002  r          r
   25 P02.04    41.72   -47.37   f 0.0000   f 0.0000   r
   26 S03.01    44.72     0.00   r          r          r
   27 S03.02    49.44     0.00   r          r          r


Spring Information at node points:

k's = k/ft or ft-k/rad.;  d's = ft or rad.
node   spring      k1      d1      k2      d2
```

```
    #    name
    8  P01X01       136.37  0.149         0.00  1.000         0.00 1000.000
    9  P01X02       414.83  0.105         0.00  1.000         0.00 1000.000
   10  P01X03       665.70  0.106         0.00  1.000         0.00 1000.000
   22  P02X01       136.37  0.149         0.00  1.000         0.00 1000.000
   23  P02X02       414.83  0.105         0.00  1.000         0.00 1000.000
   24  P02X03       665.70  0.106         0.00  1.000         0.00 1000.000


Structural Setup:
Spans= 3, Columns= 2, Piles= 2, Link Beams= 0


Element Information:
   element     nodes      depth
 # name fix    i  j      L   d   area    Ei     Ef     Icr     q     Mpp    Mpn  tol
status
  1 S01-01 rn   1   2   4.72 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
  2 S01-02 rn   2   3   3.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
  3 C01-01 rn   3   4   3.38 6.0 28.3 629528  62953  47.44   0.00  27676  27676 0.02 e
  4 C01-02 rn   4   5  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
  5 C01-03 rn   5   6  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
  6 C01-04 rn   6   7  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
  7 P01-01 rn   7   8   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
  8 P01-02 rn   8   9   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
  9 P01-03 rn   9  10   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 10 P01-04 rn  10  11   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 11 S02-01 rn   3  12   3.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 12 S02-02 rn  12  13   7.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 13 S02-03 rn  13  14   7.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 14 S02-04 rn  14  15   7.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 15 S02-05 rn  15  16   7.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 16 S02-06 rn  16  17   3.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 17 C02-01 rn  17  18   3.38 6.0 28.3 629528  62953  47.44   0.00  27676  27676 0.02 e
 18 C02-02 rn  18  19  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 19 C02-03 rn  19  20  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 20 C02-04 rn  20  21  11.93 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 21 P02-01 rn  21  22   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 22 P02-02 rn  22  23   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 23 P02-03 rn  23  24   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 24 P02-04 rn  24  25   2.05 6.0 28.3 629528  62953  23.72   0.00  13838  13838 0.02 e
 25 S03-01 rn  17  26   3.00 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
 26 S03-02 rn  26  27   4.72 6.8 62.6 629528  62953  52.25 -68.40  27676  27676 0.02 e
bandwidth of the problem = 10
Number of rows and columns in strage = 81 x 30


Cumulative Results of analysis at end of stage   0

Plastic Action at:
                      Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL= 3381.7)  /    (in)

node# name   ---------- GLOBAL ---------
             Displ.x  Displ.y  Rotation
    1 S01.00  0.00001  0.00633 -0.00136
    2 S01.01  0.00001 -0.00014 -0.00140
    3 S01.02  0.00001 -0.00450 -0.00152
    4 C01.01 -0.00484 -0.00418 -0.00135
    5 C01.02 -0.01446 -0.00304 -0.00032
    6 C01.03 -0.01376 -0.00191  0.00038
    7 C01.04 -0.00662 -0.00078  0.00076
    8 P01.01 -0.00503 -0.00058  0.00079
    9 P01.02 -0.00338 -0.00039  0.00081
   10 P01.03 -0.00170 -0.00019  0.00083
   11 P01.04  0.00000  0.00000  0.00083
   12 S02.01  0.00001 -0.00941 -0.00170
   13 S02.02  0.00000 -0.02023 -0.00121
```

```
   14 S02.03 -0.00001 -0.02467  0.00000
   15 S02.04 -0.00001 -0.02023  0.00121
   16 S02.05 -0.00002 -0.00941  0.00170
   17 S02.06 -0.00002 -0.00450  0.00152
   18 C02.01  0.00483 -0.00417  0.00135
   19 C02.02  0.01445 -0.00304  0.00032
   20 C02.03  0.01375 -0.00191 -0.00038
   21 C02.04  0.00662 -0.00078 -0.00076
   22 P02.01  0.00503 -0.00058 -0.00079
   23 P02.02  0.00338 -0.00039 -0.00081
   24 P02.03  0.00170 -0.00019 -0.00083
   25 P02.04  0.00000  0.00000 -0.00083
   26 S03.01 -0.00002 -0.00014  0.00140
   27 S03.02 -0.00002  0.00633  0.00136

element   node  -------- local -----------  ------ element ----------
#    name  fix    displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1  0.00001  0.00633 -0.00136      0.00      0.00      0.00
                2  0.00001 -0.00014 -0.00140      0.00    322.85   -761.94
  2 S01-02 rn   2  0.00001 -0.00014 -0.00140      0.00   -322.85    761.93
                3  0.00001 -0.00450 -0.00152      0.00    528.05  -2038.28
  3 C01-01 rn   3  0.00450  0.00001 -0.00152   1690.85    -34.15  -1605.41
                4  0.00418 -0.00484 -0.00135  -1690.85     34.15   1489.98
  4 C01-02 rn   4  0.00418 -0.00484 -0.00135   1690.85    -34.15  -1489.98
                5  0.00304 -0.01446 -0.00032  -1690.85     34.15   1082.57
  5 C01-03 rn   5  0.00304 -0.01446 -0.00032   1690.85    -34.15  -1082.57
                6  0.00191 -0.01376  0.00038  -1690.85     34.15    675.15
  6 C01-04 rn   6  0.00191 -0.01376  0.00038   1690.85    -34.15   -675.15
                7  0.00078 -0.00662  0.00076  -1690.85     34.15    267.73
  7 P01-01 rn   7  0.00078 -0.00662  0.00076   1690.85    -34.14   -267.71
                8  0.00058 -0.00503  0.00079  -1690.85     34.14    197.70
  8 P01-02 rn   8  0.00058 -0.00503  0.00079   1690.85    -33.46   -197.70
                9  0.00039 -0.00338  0.00081  -1690.85     33.46    129.10
  9 P01-03 rn   9  0.00039 -0.00338  0.00081   1690.85    -32.05   -129.10
               10  0.00019 -0.00170  0.00083  -1690.85     32.05     63.39
 10 P01-04 rn  10  0.00019 -0.00170  0.00083   1690.85    -30.92    -63.40
               11  0.00000  0.00000  0.00083  -1690.85     30.92      0.00
 11 S02-01 rn   3  0.00001 -0.00450 -0.00152     34.15   1162.80   3643.68
               12  0.00001 -0.00941 -0.00170    -34.15   -957.60   -463.07
 12 S02-02 rn  12  0.00001 -0.00941 -0.00170     34.15    957.61    463.06
               13  0.00000 -0.02023 -0.00121    -34.15   -478.81   4564.38
 13 S02-03 rn  13  0.00000 -0.02023 -0.00121     34.15    478.81  -4564.38
               14 -0.00001 -0.02467  0.00000    -34.15     -0.01   6240.23
 14 S02-04 rn  14 -0.00001 -0.02467  0.00000     34.15      0.01  -6240.23
               15 -0.00001 -0.02023  0.00121    -34.15    478.79   4564.47
 15 S02-05 rn  15 -0.00001 -0.02023  0.00121     34.15   -478.80  -4564.46
               16 -0.00002 -0.00941  0.00170    -34.15    957.60   -462.91
 16 S02-06 rn  16 -0.00002 -0.00941  0.00170     34.15   -957.59    462.89
               17 -0.00002 -0.00450  0.00152    -34.15   1162.79  -3643.48
 17 C02-01 rn  17  0.00450 -0.00002  0.00152   1690.83     34.15   1605.20
               18  0.00417  0.00483  0.00135  -1690.83    -34.15  -1489.77
 18 C02-02 rn  18  0.00417  0.00483  0.00135   1690.83     34.15   1489.77
               19  0.00304  0.01445  0.00032  -1690.83    -34.15  -1082.42
 19 C02-03 rn  19  0.00304  0.01445  0.00032   1690.83     34.15   1082.42
               20  0.00191  0.01375 -0.00038  -1690.83    -34.15   -675.06
 20 C02-04 rn  20  0.00191  0.01375 -0.00038   1690.83     34.15    675.06
               21  0.00078  0.00662 -0.00076  -1690.83    -34.15   -267.70
 21 P02-01 rn  21  0.00078  0.00662 -0.00076   1690.83     34.14    267.71
               22  0.00058  0.00503 -0.00079  -1690.83    -34.14   -197.71
 22 P02-02 rn  22  0.00058  0.00503 -0.00079   1690.83     33.46    197.71
               23  0.00039  0.00338 -0.00081  -1690.83    -33.46   -129.11
 23 P02-03 rn  23  0.00039  0.00338 -0.00081   1690.83     32.06    129.12
               24  0.00019  0.00170 -0.00083  -1690.83    -32.06    -63.39
 24 P02-04 rn  24  0.00019  0.00170 -0.00083   1690.83     30.93     63.40
               25  0.00000  0.00000 -0.00083  -1690.83    -30.93      0.00
 25 S03-01 rn  17 -0.00002 -0.00450  0.00152      0.00    528.05   2038.28
               26 -0.00002 -0.00014  0.00140      0.00   -322.85   -761.92
 26 S03-02 rn  26 -0.00002 -0.00014  0.00140      0.00    322.85    761.93
```

```
              27 -0.00002  0.00633  0.00136      0.00      0.00      0.00


Cumulative Results of analysis at end of stage   1

Plastic Action at:
                      Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL= 3381.7)  /     (in)
C02-02     1     rs       0.1712          8.4898

node# name   ---------- GLOBAL ---------
             Displ.x  Displ.y  Rotation
    1 S01.00  0.70748  0.02708 -0.00378
    2 S01.01  0.70748  0.00919 -0.00382
    3 S01.02  0.70747 -0.00241 -0.00394
    4 C01.01  0.69197 -0.00224 -0.00522
    5 C01.02  0.58279 -0.00163 -0.01268
    6 C01.03  0.39898 -0.00103 -0.01773
    7 C01.04  0.16941 -0.00042 -0.02035
    8 P01.01  0.12746 -0.00031 -0.02056
    9 P01.02  0.08515 -0.00021 -0.02070
   10 P01.03  0.04263 -0.00010 -0.02078
   11 P01.04  0.00000  0.00000 -0.02080
   12 S02.01  0.70749 -0.01286 -0.00301
   13 S02.02  0.70750 -0.02604 -0.00077
   14 S02.03  0.70750 -0.02467  0.00103
   15 S02.04  0.70749 -0.01442  0.00165
   16 S02.05  0.70746 -0.00595  0.00039
   17 S02.06  0.70744 -0.00658 -0.00090
   18 C02.01  0.70163 -0.00611 -0.00252
   19 C02.02  0.61168 -0.00445 -0.01204
   20 C02.03  0.42648 -0.00280 -0.01849
   21 C02.04  0.18265 -0.00114 -0.02187
   22 P02.01  0.13751 -0.00085 -0.02214
   23 P02.02  0.09192 -0.00057 -0.02233
   24 P02.03  0.04603 -0.00028 -0.02243
   25 P02.04  0.00000  0.00000 -0.02246
   26 S03.01  0.70745 -0.00948 -0.00102
   27 S03.02  0.70745 -0.01442 -0.00106

element   node  -------- local -----------  ------ element ----------
#    name  fix     displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1  0.70748  0.02708 -0.00378     27.69     -0.01     -0.01
                2  0.70748  0.00919 -0.00382    -27.69    322.85   -761.97
  2 S01-02 rn   2  0.70748  0.00919 -0.00382     71.78   -322.85    761.95
                3  0.70747 -0.00241 -0.00394    -71.78    528.05  -2038.29
  3 C01-01 rn   3  0.00241  0.70747 -0.00394    907.25    253.50  11715.99
                4  0.00224  0.69197 -0.00522   -907.25   -253.50 -10859.41
  4 C01-02 rn   4  0.00224  0.69197 -0.00522    907.18    253.90  10859.10
                5  0.00163  0.58279 -0.01268   -907.18   -253.90  -7830.08
  5 C01-03 rn   5  0.00163  0.58279 -0.01268    907.18    253.90   7830.12
                6  0.00103  0.39898 -0.01773   -907.18   -253.90  -4801.02
  6 C01-04 rn   6  0.00103  0.39898 -0.01773    907.18    253.90   4801.03
                7  0.00042  0.16941 -0.02035   -907.18   -253.90  -1771.96
  7 P01-01 rn   7  0.00042  0.16941 -0.02035    907.18    253.53   1771.40
                8  0.00031  0.12746 -0.02056   -907.18   -253.53  -1250.91
  8 P01-02 rn   8  0.00031  0.12746 -0.02056    907.18    236.71   1251.16
                9  0.00021  0.08515 -0.02070   -907.18   -236.71   -765.72
  9 P01-03 rn   9  0.00021  0.08515 -0.02070    907.18    201.31    766.32
               10  0.00010  0.04263 -0.02078   -907.18   -201.31   -353.62
 10 P01-04 rn  10  0.00010  0.04263 -0.02078    907.18    172.67    354.11
               11  0.00000  0.00000 -0.02080   -907.18   -172.67      0.01
 11 S02-01 rn   3  0.70747 -0.00241 -0.00394   -147.11    379.20  -9677.96
               12  0.70749 -0.01286 -0.00301    147.11   -174.00  10507.76
 12 S02-02 rn  12  0.70749 -0.01286 -0.00301    -88.03    173.93 -10507.76
               13  0.70750 -0.02604 -0.00077     88.03    304.87  10049.47
 13 S02-03 rn  13  0.70750 -0.02604 -0.00077     -5.78   -304.87 -10049.47
```

```
                 14  0.70750 -0.02467  0.00103      5.78    783.67   6239.57
14 S02-04 rn  14  0.70750 -0.02467  0.00103     76.09   -783.67  -6239.57
                 15  0.70749 -0.01442  0.00165    -76.09   1262.47   -921.93
15 S02-05 rn  15  0.70749 -0.01442  0.00165    158.08  -1262.47    921.94
                 16  0.70746 -0.00595  0.00039   -158.08   1741.27 -11435.05
16 S02-06 rn  16  0.70746 -0.00595  0.00039    216.23  -1741.27  11435.04
                 17  0.70744 -0.00658 -0.00090   -216.23   1946.47 -16966.67
17 C02-01 rn  17  0.00658  0.70744 -0.00090   2474.51    322.57  14926.95
                 18  0.00611  0.70163 -0.00252  -2474.51   -322.57 -13838.61
18 C02-02 rs  18  0.00611  0.70163 -0.00252   2474.46    322.17  13838.00
                 19  0.00445  0.61168 -0.01204  -2474.46   -322.17  -9994.56
19 C02-03 rn  19  0.00445  0.61168 -0.01204   2474.46    322.18   9994.59
                 20  0.00280  0.42648 -0.01849  -2474.46   -322.18  -6150.91
20 C02-04 rn  20  0.00280  0.42648 -0.01849   2474.46    322.18   6150.92
                 21  0.00114  0.18265 -0.02187  -2474.46   -322.18  -2307.32
21 P02-01 rn  21  0.00114  0.18265 -0.02187   2474.46    322.17   2307.40
                 22  0.00085  0.13751 -0.02214  -2474.46   -322.17  -1646.88
22 P02-02 rn  22  0.00085  0.13751 -0.02214   2474.46    303.41   1647.21
                 23  0.00057  0.09192 -0.02233  -2474.46   -303.41  -1024.71
23 P02-03 rn  23  0.00057  0.09192 -0.02233   2474.46    265.35   1024.96
                 24  0.00028  0.04603 -0.02243  -2474.46   -265.35   -481.13
24 P02-04 rn  24  0.00028  0.04603 -0.02243   2474.46    234.74    481.23
                 25  0.00000  0.00000 -0.02246  -2474.46   -234.74      0.07
25 S03-01 rn  17  0.70744 -0.00658 -0.00090    -72.95    528.06   2038.30
                 26  0.70745 -0.00948 -0.00102     72.95   -322.86   -761.92
26 S03-02 rn  26  0.70745 -0.00948 -0.00102    -28.11    322.85    761.91
                 27  0.70745 -0.01442 -0.00106     28.11      0.00      0.00
```

## APPENDIX – K

(Output from xSECTION)

```
05/10/2006, 07:43
************************************************************
*                                                          *
*                       xSECTION                           *
*                                                          *
*               DUCTILITY and STRENGTH of                  *
*      Circular, Semi-Circular, full and partial Rings,    *
*   Rectangular, T-, I-, Hammer head, Octagonal, Polygons  *
*       or any combination of above shapes forming         *
*          Concrete Sections using Fiber Models            *
*                                                          *
* VER._2.40,_MAR-14-99                                     *
*                                                          *
* Copyright (C) 1994, 1995, 1999 By Mark Seyed Mahan.      *
*                                                          *
* A proper license must be obtained to use this software.  *
* For GOVERNMENT work call 916-227-8404, otherwise leave a *
* message at 530-756-2367. The author makes no expressed or*
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for          *
* incidental or consequential damages arising out of the   *
* use of this program.                                     *
*                                                          *
************************************************************
This output was generated by running:
xSECTION
VER._2.40,_MAR-14-99
LICENSE    (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY     (choices: GOVERNMENT/CONSULTANT)
Government
NAME_OF_FIRM
Caltrans
BRIDGE_NAME
EXAMPLE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY


Concrete Type Information:

     ----------strains--------  --------strength--------
Type   e0     e2     ecc     eu     f0    f2    fcc    fu    E     W
 1 0.0020 0.0040 0.0055 0.0145  5.28  6.98  7.15  6.11  4313   148
 2 0.0020 0.0040 0.0020 0.0050  5.28  3.61  5.28  2.64  4313   148


Steel Type Information:

     -----strains------  --strength-
Type  ey     eh     eu    fy    fu    E
 1 0.0023 0.0150 0.0900 68.00 95.00 29000
 2 0.0023 0.0075 0.0600 68.00 95.00 29000


Steel Fiber Information:

Fiber          xc       yc      area
No.   type     in       in      in^2
  1    2    31.93    0.00    2.25
  2    2    31.00    7.64    2.25
  3    2    28.27   14.84    2.25
  4    2    23.90   21.17    2.25
  5    2    18.14   26.28    2.25
  6    2    11.32   29.86    2.25
```

| | | | | |
|---|---|---|---|---|
| 7 | 2 | 3.85 | 31.70 | 2.25 |
| 8 | 2 | -3.85 | 31.70 | 2.25 |
| 9 | 2 | -11.32 | 29.86 | 2.25 |
| 10 | 2 | -18.14 | 26.28 | 2.25 |
| 11 | 2 | -23.90 | 21.17 | 2.25 |
| 12 | 2 | -28.27 | 14.84 | 2.25 |
| 13 | 2 | -31.00 | 7.64 | 2.25 |
| 14 | 2 | -31.93 | 0.00 | 2.25 |
| 15 | 2 | -31.00 | -7.64 | 2.25 |
| 16 | 2 | -28.27 | -14.84 | 2.25 |
| 17 | 2 | -23.90 | -21.17 | 2.25 |
| 18 | 2 | -18.14 | -26.28 | 2.25 |
| 19 | 2 | -11.32 | -29.86 | 2.25 |
| 20 | 2 | -3.85 | -31.70 | 2.25 |
| 21 | 2 | 3.85 | -31.70 | 2.25 |
| 22 | 2 | 11.32 | -29.85 | 2.25 |
| 23 | 2 | 18.14 | -26.28 | 2.25 |
| 24 | 2 | 23.90 | -21.17 | 2.25 |
| 25 | 2 | 28.27 | -14.84 | 2.25 |
| 26 | 2 | 31.00 | -7.64 | 2.25 |

Force Equilibrium Condition of the x-section:

| step | Max. Conc. Strain epscmax | Neutral Axis in. | Max. Steel Strain Tens. | Conc. Comp. | Steel force Comp. | Steel force Tens. | P/S force | Net force | Curvature rad/in | Moment (K-ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00000 | 0.00 | 0.0000 | 0 | 0 | 0 | 0 | 0.00 | 0.000000 | 0 |
| 1 | 0.00029 | -29.19 | 0.0000 | 2256 | 222 | -2 | 0 | 1.88 | 0.000004 | 2346 |
| 2 | 0.00032 | -23.84 | 0.0000 | 2255 | 228 | -11 | 0 | -2.06 | 0.000005 | 2726 |
| 3 | 0.00035 | -19.33 | -0.0001 | 2264 | 237 | -26 | 0 | -0.29 | 0.000006 | 3094 |
| 4 | 0.00039 | -15.36 | -0.0001 | 2275 | 246 | -47 | 0 | -0.08 | 0.000008 | 3457 |
| 5 | 0.00043 | -11.84 | -0.0002 | 2291 | 258 | -76 | 0 | -1.19 | 0.000009 | 3820 |
| 6 | 0.00048 | -8.79 | -0.0002 | 2317 | 271 | -112 | 0 | 1.96 | 0.000011 | 4189 |
| 7 | 0.00053 | -6.03 | -0.0003 | 2347 | 286 | -157 | 0 | 2.28 | 0.000013 | 4569 |
| 8 | 0.00059 | -3.59 | -0.0004 | 2383 | 302 | -212 | 0 | -0.48 | 0.000015 | 4967 |
| 9 | 0.00065 | -1.45 | -0.0005 | 2431 | 319 | -277 | 0 | -0.18 | 0.000017 | 5390 |
| 10 | 0.00072 | 0.46 | -0.0006 | 2490 | 338 | -354 | 0 | 0.01 | 0.000020 | 5841 |
| 11 | 0.00079 | 2.09 | -0.0008 | 2557 | 362 | -445 | 0 | 0.31 | 0.000023 | 6331 |
| 12 | 0.00087 | 3.60 | -0.0010 | 2637 | 387 | -552 | 0 | -1.88 | 0.000027 | 6859 |
| 13 | 0.00097 | 4.88 | -0.0011 | 2732 | 414 | -672 | 0 | 0.84 | 0.000031 | 7435 |
| 14 | 0.00107 | 6.00 | -0.0013 | 2836 | 444 | -807 | 0 | -0.59 | 0.000036 | 8061 |
| 15 | 0.00118 | 6.94 | -0.0016 | 2954 | 477 | -956 | 0 | 0.74 | 0.000041 | 8740 |
| 16 | 0.00131 | 7.76 | -0.0018 | 3083 | 513 | -1123 | 0 | 0.17 | 0.000046 | 9477 |
| 17 | 0.00144 | 8.49 | -0.0021 | 3230 | 558 | -1314 | 0 | -0.45 | 0.000053 | 10276 |
| 18 | 0.00160 | 9.12 | -0.0024 | 3389 | 607 | -1519 | 0 | 2.42 | 0.000059 | 11119 |
| 19 | 0.00176 | 9.96 | -0.0028 | 3497 | 655 | -1677 | 0 | 1.32 | 0.000068 | 11722 |
| 20 | 0.00195 | 10.82 | -0.0033 | 3579 | 706 | -1812 | 0 | -1.62 | 0.000078 | 12213 |
| 21 | 0.00216 | 11.66 | -0.0038 | 3650 | 758 | -1935 | 0 | -0.48 | 0.000089 | 12638 |
| 22 | 0.00238 | 12.54 | -0.0045 | 3692 | 811 | -2029 | 0 | 0.16 | 0.000102 | 12957 |
| 23 | 0.00264 | 13.30 | -0.0052 | 3731 | 869 | -2124 | 0 | 2.31 | 0.000116 | 13266 |
| 24 | 0.00291 | 14.11 | -0.0061 | 3742 | 926 | -2194 | 0 | 0.52 | 0.000133 | 13492 |
| 25 | 0.00322 | 14.74 | -0.0070 | 3778 | 963 | -2268 | 0 | -1.28 | 0.000152 | 13683 |
| 26 | 0.00356 | 15.28 | -0.0081 | 3813 | 991 | -2330 | 0 | 0.34 | 0.000172 | 13834 |
| 27 | 0.00394 | 15.73 | -0.0092 | 3856 | 1018 | -2399 | 0 | 0.71 | 0.000194 | 14012 |
| 28 | 0.00435 | 16.07 | -0.0104 | 3904 | 1049 | -2478 | 0 | 0.63 | 0.000219 | 14204 |
| 29 | 0.00481 | 16.24 | -0.0117 | 3950 | 1075 | -2552 | 0 | -0.48 | 0.000244 | 14332 |
| 30 | 0.00532 | 16.23 | -0.0129 | 4008 | 1092 | -2623 | 0 | 1.90 | 0.000269 | 14424 |
| 31 | 0.00588 | 16.38 | -0.0144 | 4043 | 1106 | -2675 | 0 | -0.34 | 0.000300 | 14544 |
| 32 | 0.00650 | 16.52 | -0.0161 | 4089 | 1121 | -2734 | 0 | 1.91 | 0.000334 | 14706 |
| 33 | 0.00718 | 16.66 | -0.0180 | 4135 | 1137 | -2797 | 0 | 0.76 | 0.000372 | 14879 |
| 34 | 0.00794 | 16.77 | -0.0200 | 4180 | 1156 | -2862 | 0 | 0.35 | 0.000414 | 15055 |
| 35 | 0.00878 | 16.86 | -0.0223 | 4226 | 1177 | -2928 | 0 | 1.07 | 0.000459 | 15231 |
| 36 | 0.00971 | 16.91 | -0.0248 | 4271 | 1201 | -2997 | 0 | 0.93 | 0.000509 | 15403 |
| 37 | 0.01073 | 16.97 | -0.0275 | 4310 | 1231 | -3069 | 0 | -2.02 | 0.000565 | 15573 |
| 38 | 0.01186 | 16.96 | -0.0304 | 4366 | 1242 | -3132 | 0 | 1.47 | 0.000624 | 15730 |
| 39 | 0.01312 | 16.95 | -0.0335 | 4415 | 1255 | -3195 | 0 | 0.47 | 0.000689 | 15869 |

## APPENDIX – K

(Output from xSECTION) – Continues

```
40   0.01450   16.91 -0.0370  4458  1269 -3255     0     -1.79 0.000761   15987


First Yield of Rebar Information (not Idealized):

     Rebar Number 20
     Coordinates X and Y (global in.)  -3.85, -31.70
     Yield strain =  0.00230
     Curvature (rad/in)=  0.000057
     Moment (ft-k) =   10802


Cross Section Information:

     Axial Load on Section (kips) =  2474
     Percentage of Main steel in Cross Section =   1.44
     Concrete modulus used in Idealization (ksi) =  4313
     Cracked Moment of Inertia (ft^4) =    25.572


Idealization of Moment-Curvature Curve by Various Methods:


                  Points on Curve        Idealized Values
                  ===============   ============================
Method     Conc.                    Yield         symbol  Plastic
 ID      | Strain  Curv.   Moment | Curv.  Moment   for   Curv.
         | in/in   rad/in  (K-ft) | rad/in (K-ft)  moment rad/in
Strain @ 0.003   0.000138   13546 0.000071   13546   Mn  0.000689
Strain @ 0.004   0.000198   14042 0.000074   14042   Mn  0.000687
Strain @ 0.005   0.000253   14366 0.000075   14366   Mn  0.000685
CALTRANS 0.00755 0.000392   14964 0.000079   14964   Mp  0.000682
UCSD@5phy0.00558 0.000283   14479 0.000076   14479   Mn  0.000685
************************************************************
```

# APPENDIX – L

(*wFRAME* Output File)

```
05/15/2006, 08:02
Design Academy Example No: 1 (Bent 2)

************************************************************
*                                                          *
*                       wFRAME                             *
*                                                          *
*         PUSH ANALYSIS of BRIDGE BENTS and FRAMES.        *
*                                                          *
*      Indicates formation of successive plastic hinges.   *
*                                                          *
* VER._1.12,_JAN-14-95                                     *
*                                                          *
* Copyright (C) 1994 By Mark Seyed.                        *
*                                                          *
* This program should not be distributed under any         *
* condition. This release is for demo ONLY (beta testing   *
* is not complete). The author makes no expressed or       *
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for          *
* incidental or consequential damages arising out of the   *
* use of this program.                                     *
*                                                          *
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Node Point Information:

Fixity condition definitions:
    s=spring and value
    r=complete release
    f=complete fixity with imposed displacement

node    name    coordinates    -----------fixity --------
  #              X       Y     X-dir.     Y-dir.   Rotation
    1 S01.00     0.00     0.00   r          r          r
    2 S01.01     4.72     0.00   r          r          r
    3 S01.02     7.72     0.00   r          r          r
    4 C01.01     7.72    -3.38   r          r          r
    5 C01.02     7.72   -15.31   r          r          r
    6 C01.03     7.72   -27.24   r          r          r
    7 C01.04     7.72   -39.17   r          r          r
    8 P01.01     7.72   -41.22   s 1.4e+002  r          r
    9 P01.02     7.72   -43.27   s 4.1e+002  r          r
   10 P01.03     7.72   -45.32   s 6.7e+002  r          r
   11 P01.04     7.72   -47.37   f 0.0000   f 0.0000   r
   12 S02.01    10.72     0.00   r          r          r
   13 S02.02    17.72     0.00   r          r          r
   14 S02.03    24.72     0.00   r          r          r
   15 S02.04    31.72     0.00   r          r          r
   16 S02.05    38.72     0.00   r          r          r
   17 S02.06    41.72     0.00   r          r          r
   18 C02.01    41.72    -3.38   r          r          r
   19 C02.02    41.72   -15.31   r          r          r
   20 C02.03    41.72   -27.24   r          r          r
   21 C02.04    41.72   -39.17   r          r          r
   22 P02.01    41.72   -41.22   s 1.4e+002  r          r
   23 P02.02    41.72   -43.27   s 4.1e+002  r          r
   24 P02.03    41.72   -45.32   s 6.7e+002  r          r
   25 P02.04    41.72   -47.37   f 0.0000   f 0.0000   r
   26 S03.01    44.72     0.00   r          r          r
   27 S03.02    49.44     0.00   r          r          r


Spring Information at node points:

k's = k/ft or ft-k/rad.;  d's = ft or rad.
```

```
node   spring      k1      d1      k2      d2
  #    name
    8  P01X01       136.37  0.149         0.00  1.000          0.00 1000.000
    9  P01X02       414.83  0.105         0.00  1.000          0.00 1000.000
   10  P01X03       665.70  0.106         0.00  1.000          0.00 1000.000
   22  P02X01       136.37  0.149         0.00  1.000          0.00 1000.000
   23  P02X02       414.83  0.105         0.00  1.000          0.00 1000.000
   24  P02X03       665.70  0.106         0.00  1.000          0.00 1000.000


Structural Setup:
Spans= 3, Columns= 2, Piles= 2, Link Beams= 0


Element Information:
   element     nodes      depth
 # name fix    i  j     L   d   area    Ei      Ef      Icr     q     Mpp    Mpn  tol
status
  1 S01-01 rn   1   2   4.72 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
  2 S01-02 rn   2   3   3.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
  3 C01-01 rn   3   4   3.38 6.0 28.3 629528  62953  43.00   0.00  29928  29928 0.02 e
  4 C01-02 rn   4   5  11.93 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
  5 C01-03 rn   5   6  11.93 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
  6 C01-04 rn   6   7  11.93 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
  7 P01-01 rn   7   8   2.05 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
  8 P01-02 rn   8   9   2.05 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
  9 P01-03 rn   9  10   2.05 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
 10 P01-04 rn  10  11   2.05 6.0 28.3 629528  62953  21.50   0.00  12636  12636 0.02 e
 11 S02-01 rn   3  12   3.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 12 S02-02 rn  12  13   7.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 13 S02-03 rn  13  14   7.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 14 S02-04 rn  14  15   7.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 15 S02-05 rn  15  16   7.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 16 S02-06 rn  16  17   3.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 17 C02-01 rn  17  18   3.38 6.0 28.3 629528  62953  51.14   0.00  29928  29928 0.02 e
 18 C02-02 rn  18  19  11.93 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 19 C02-03 rn  19  20  11.93 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 20 C02-04 rn  20  21  11.93 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 21 P02-01 rn  21  22   2.05 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 22 P02-02 rn  22  23   2.05 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 23 P02-03 rn  23  24   2.05 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 24 P02-04 rn  24  25   2.05 6.0 28.3 629528  62953  25.57   0.00  14964  14964 0.02 e
 25 S03-01 rn  17  26   3.00 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
 26 S03-02 rn  26  27   4.72 6.8 62.6 629528  62953  52.25 -68.40  29928  29928 0.02 e
bandwidth of the problem = 10
Number of rows and columns in strage = 81 x 30


Cumulative Results of analysis at end of stage   0

Plastic Action at:
                      Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL= 3381.7)  /    (in)

node# name   ---------- GLOBAL ---------
             Displ.x  Displ.y  Rotation
    1 S01.00 -0.00603  0.00640 -0.00137
    2 S01.01 -0.00603 -0.00012 -0.00141
    3 S01.02 -0.00603 -0.00450 -0.00153
    4 C01.01 -0.01088 -0.00417 -0.00134
    5 C01.02 -0.01983 -0.00304 -0.00022
    6 C01.03 -0.01753 -0.00191  0.00054
    7 C01.04 -0.00824 -0.00078  0.00095
    8 P01.01 -0.00625 -0.00058  0.00099
    9 P01.02 -0.00420 -0.00039  0.00101
   10 P01.03 -0.00211 -0.00019  0.00103
   11 P01.04  0.00000  0.00000  0.00103
```

```
   12 S02.01 -0.00603 -0.00943 -0.00171
   13 S02.02 -0.00604 -0.02029 -0.00121
   14 S02.03 -0.00604 -0.02474  0.00000
   15 S02.04 -0.00605 -0.02029  0.00121
   16 S02.05 -0.00606 -0.00943  0.00171
   17 S02.06 -0.00606 -0.00450  0.00153
   18 C02.01 -0.00116 -0.00418  0.00137
   19 C02.02  0.00923 -0.00304  0.00042
   20 C02.03  0.01011 -0.00191 -0.00022
   21 C02.04  0.00506 -0.00078 -0.00057
   22 P02.01  0.00386 -0.00058 -0.00060
   23 P02.02  0.00260 -0.00039 -0.00062
   24 P02.03  0.00131 -0.00019 -0.00064
   25 P02.04  0.00000  0.00000 -0.00064
   26 S03.01 -0.00606 -0.00012  0.00141
   27 S03.02 -0.00606  0.00639  0.00137

element   node  -------- local -----------  ------ element ----------
#    name  fix    displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1 -0.00603  0.00640 -0.00137      0.00      0.00      0.00
                2 -0.00603 -0.00012 -0.00141      0.00    322.85   -761.94
  2 S01-02 rn   2 -0.00603 -0.00012 -0.00141      0.01   -322.84    761.93
                3 -0.00603 -0.00450 -0.00153     -0.01    528.04  -2038.28
  3 C01-01 rn   3  0.00450 -0.00603 -0.00153   1690.68    -33.83  -1586.95
                4  0.00417 -0.01088 -0.00134  -1690.68     33.83   1472.63
  4 C01-02 rn   4  0.00417 -0.01088 -0.00134   1690.68    -33.83  -1472.62
                5  0.00304 -0.01983 -0.00022  -1690.68     33.83   1069.07
  5 C01-03 rn   5  0.00304 -0.01983 -0.00022   1690.68    -33.83  -1069.07
                6  0.00191 -0.01753  0.00054  -1690.68     33.83    665.52
  6 C01-04 rn   6  0.00191 -0.01753  0.00054   1690.68    -33.83   -665.52
                7  0.00078 -0.00824  0.00095  -1690.68     33.83    261.97
  7 P01-01 rn   7  0.00078 -0.00824  0.00095   1690.68    -33.81   -261.97
                8  0.00058 -0.00625  0.00099  -1690.68     33.81    192.69
  8 P01-02 rn   8  0.00058 -0.00625  0.00099   1690.68    -32.97   -192.66
                9  0.00039 -0.00420  0.00101  -1690.68     32.97    125.08
  9 P01-03 rn   9  0.00039 -0.00420  0.00101   1690.68    -31.21   -125.08
               10  0.00019 -0.00211  0.00103  -1690.68     31.21     61.11
 10 P01-04 rn  10  0.00019 -0.00211  0.00103   1690.68    -29.81    -61.10
               11  0.00000  0.00000  0.00103  -1690.68     29.81      0.00
 11 S02-01 rn   3 -0.00603 -0.00450 -0.00153     33.83   1162.63   3625.24
               12 -0.00603 -0.00943 -0.00171    -33.83   -957.43   -445.14
 12 S02-02 rn  12 -0.00603 -0.00943 -0.00171     33.84    957.44    445.15
               13 -0.00604 -0.02029 -0.00121    -33.84   -478.64   4581.10
 13 S02-03 rn  13 -0.00604 -0.02029 -0.00121     33.84    478.64  -4581.10
               14 -0.00604 -0.02474  0.00000    -33.84      0.16   6255.76
 14 S02-04 rn  14 -0.00604 -0.02474  0.00000     33.83     -0.17  -6255.76
               15 -0.00605 -0.02029  0.00121    -33.83    478.97   4578.80
 15 S02-05 rn  15 -0.00605 -0.02029  0.00121     33.83   -478.97  -4578.80
               16 -0.00606 -0.00943  0.00171    -33.83    957.77   -449.77
 16 S02-06 rn  16 -0.00606 -0.00943  0.00171     33.83   -957.76    449.74
               17 -0.00606 -0.00450  0.00153    -33.83   1162.96  -3630.83
 17 C02-01 rn  17  0.00450 -0.00606  0.00153   1691.01     33.82   1592.56
               18  0.00418 -0.00116  0.00137  -1691.01    -33.82  -1478.22
 18 C02-02 rn  18  0.00418 -0.00116  0.00137   1691.01     33.82   1478.23
               19  0.00304  0.00923  0.00042  -1691.01    -33.82  -1074.75
 19 C02-03 rn  19  0.00304  0.00923  0.00042   1691.01     33.82   1074.75
               20  0.00191  0.01011 -0.00022  -1691.01    -33.82   -671.27
 20 C02-04 rn  20  0.00191  0.01011 -0.00022   1691.01     33.82    671.27
               21  0.00078  0.00506 -0.00057  -1691.01    -33.82   -267.80
 21 P02-01 rn  21  0.00078  0.00506 -0.00057   1691.01     33.82    267.81
               22  0.00058  0.00386 -0.00060  -1691.01    -33.82   -198.48
 22 P02-02 rn  22  0.00058  0.00386 -0.00060   1691.01     33.29    198.49
               23  0.00039  0.00260 -0.00062  -1691.01    -33.29   -130.25
 23 P02-03 rn  23  0.00039  0.00260 -0.00062   1691.01     32.20    130.26
               24  0.00019  0.00131 -0.00064  -1691.01    -32.20    -64.23
 24 P02-04 rn  24  0.00019  0.00131 -0.00064   1691.01     31.33     64.24
               25  0.00000  0.00000 -0.00064  -1691.01    -31.33      0.00
```

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 25 S03-01 rn  17 -0.00606 -0.00450  0.00153      0.00    528.05   2038.27
               26 -0.00606 -0.00012  0.00141      0.00   -322.85   -761.93
 26 S03-02 rn  26 -0.00606 -0.00012  0.00141      0.00    322.85    761.93
               27 -0.00606  0.00639  0.00137      0.00      0.00      0.00


Cumulative Results of analysis at end of stage   1

Plastic Action at:
                      Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL= 3381.7)  /    (in)
C02-02     1     rs       0.1760          8.7862

node# name   ---------- GLOBAL ---------
             Displ.x  Displ.y  Rotation
    1 S01.00  0.73219  0.02482 -0.00348
    2 S01.01  0.73218  0.00836 -0.00351
    3 S01.02  0.73218 -0.00234 -0.00364
    4 C01.01  0.71753 -0.00217 -0.00501
    5 C01.02  0.60724 -0.00158 -0.01304
    6 C01.03  0.41672 -0.00099 -0.01846
    7 C01.04  0.17709 -0.00040 -0.02127
    8 P01.01  0.13324 -0.00030 -0.02149
    9 P01.02  0.08902 -0.00020 -0.02164
   10 P01.03  0.04456 -0.00010 -0.02172
   11 P01.04  0.00000  0.00000 -0.02175
   12 S02.01  0.73219 -0.01192 -0.00274
   13 S02.02  0.73220 -0.02352 -0.00059
   14 S02.03  0.73220 -0.02138  0.00106
   15 S02.04  0.73218 -0.01148  0.00151
   16 S02.05  0.73215 -0.00478  0.00003
   17 S02.06  0.73213 -0.00665 -0.00137
   18 C02.01  0.72472 -0.00618 -0.00300
   19 C02.02  0.62890 -0.00450 -0.01255
   20 C02.03  0.43749 -0.00283 -0.01903
   21 C02.04  0.18720 -0.00115 -0.02242
   22 P02.01  0.14093 -0.00086 -0.02270
   23 P02.02  0.09420 -0.00058 -0.02288
   24 P02.03  0.04717 -0.00029 -0.02299
   25 P02.04  0.00000  0.00000 -0.02302
   26 S03.01  0.73214 -0.01097 -0.00149
   27 S03.02  0.73214 -0.01813 -0.00153

element   node  -------- local -----------  ------ element ----------
#    name  fix    displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1  0.73219  0.02482 -0.00348     29.06     -0.01      0.01
                2  0.73218  0.00836 -0.00351    -29.06    322.86   -761.97
  2 S01-02 rn   2  0.73218  0.00836 -0.00351     74.05   -322.85    761.94
                3  0.73218 -0.00234 -0.00364    -74.05    528.05  -2038.29
  3 C01-01 rn   3  0.00234  0.73218 -0.00364    879.83    248.18  11431.10
                4  0.00217  0.71753 -0.00501   -879.83   -248.18 -10591.82
  4 C01-02 rn   4  0.00217  0.71753 -0.00501    879.86    248.19  10591.19
                5  0.00158  0.60724 -0.01304   -879.86   -248.19  -7630.29
  5 C01-03 rn   5  0.00158  0.60724 -0.01304    879.86    248.21   7630.31
                6  0.00099  0.41672 -0.01846   -879.86   -248.21  -4669.24
  6 C01-04 rn   6  0.00099  0.41672 -0.01846    879.86    248.20   4669.30
                7  0.00040  0.17709 -0.02127   -879.86   -248.20  -1708.25
  7 P01-01 rn   7  0.00040  0.17709 -0.02127    879.86    248.12   1708.95
                8  0.00030  0.13324 -0.02149   -879.86   -248.12  -1200.10
  8 P01-02 rn   8  0.00030  0.13324 -0.02149    879.86    230.01   1200.16
                9  0.00020  0.08902 -0.02164   -879.86   -230.01   -728.78
  9 P01-03 rn   9  0.00020  0.08902 -0.02164    879.86    192.70    729.12
               10  0.00010  0.04456 -0.02172   -879.86   -192.70   -334.12
 10 P01-04 rn  10  0.00010  0.04456 -0.02172    879.86    163.00    334.16
               11  0.00000  0.00000 -0.02175   -879.86   -163.00     -0.02
 11 S02-01 rn   3  0.73218 -0.00234 -0.00364   -137.94    351.79  -9393.48
               12  0.73219 -0.01192 -0.00274    137.94   -146.59  10141.05
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 12 S02-02 rn  12  0.73219 -0.01192 -0.00274    -78.08    146.67 -10141.02
               13  0.73220 -0.02352 -0.00059     78.08    332.13   9491.90
 13 S02-03 rn  13  0.73220 -0.02352 -0.00059      6.47   -332.13  -9491.90
               14  0.73220 -0.02138  0.00106     -6.47    810.93   5491.19
 14 S02-04 rn  14  0.73220 -0.02138  0.00106     91.08   -810.93  -5491.19
               15  0.73218 -0.01148  0.00151    -91.08   1289.73  -1861.15
 15 S02-05 rn  15  0.73218 -0.01148  0.00151    175.49  -1289.73   1861.14
               16  0.73215 -0.00478  0.00003   -175.49   1768.53 -12565.08
 16 S02-06 rn  16  0.73215 -0.00478  0.00003    236.81  -1768.53  12565.06
               17  0.73213 -0.00665 -0.00137   -236.81   1973.73 -18178.47
 17 C02-01 rn  17  0.00665  0.73213 -0.00137   2501.90    348.38  16141.41
               18  0.00618  0.72472 -0.00300  -2501.90   -348.38 -14963.38
 18 C02-02 rs  18  0.00618  0.72472 -0.00300   2501.84    348.05  14964.00
               19  0.00450  0.62890 -0.01255  -2501.84   -348.05 -10811.87
 19 C02-03 rn  19  0.00450  0.62890 -0.01255   2501.84    348.04  10811.93
               20  0.00283  0.43749 -0.01903  -2501.84   -348.04  -6659.75
 20 C02-04 rn  20  0.00283  0.43749 -0.01903   2501.84    348.03   6659.80
               21  0.00115  0.18720 -0.02242  -2501.84   -348.03  -2507.76
 21 P02-01 rn  21  0.00115  0.18720 -0.02242   2501.84    347.72   2507.71
               22  0.00086  0.14093 -0.02270  -2501.84   -347.72  -1795.38
 22 P02-02 rn  22  0.00086  0.14093 -0.02270   2501.84    328.53   1795.20
               23  0.00058  0.09420 -0.02288  -2501.84   -328.53  -1121.56
 23 P02-03 rn  23  0.00058  0.09420 -0.02288   2501.84    289.56   1122.16
               24  0.00029  0.04717 -0.02299  -2501.84   -289.56   -528.43
 24 P02-04 rn  24  0.00029  0.04717 -0.02299   2501.84    257.88    528.77
               25  0.00000  0.00000 -0.02302  -2501.84   -257.88     -0.07
 25 S03-01 rn  17  0.73213 -0.00665 -0.00137    -74.72    528.17   2038.64
               26  0.73214 -0.01097 -0.00149     74.72   -322.97   -761.94
 26 S03-02 rn  26  0.73214 -0.01097 -0.00149    -28.84    322.85    761.91
               27  0.73214 -0.01813 -0.00153     28.84      0.00      0.01
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Cumulative Results of analysis at end of stage   6

Plastic Action at:
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| Element/ | Stage/ | Code/ | Lat. Force *g (DL= 3381.7) / | Deflection (in) |
|---|---|---|---|---|
| C02-02 | 1 | rs | 0.1760 | 8.7862 |
| P02X01 | 2 | 2 | 0.1818 | 9.4798 |
| P01X01 | 3 | 2 | 0.1847 | 9.8322 |
| P02X02 | 4 | 2 | 0.1875 | 10.1774 |
| P01X02 | 5 | 2 | 0.1891 | 10.3724 |
| **C01-02** | **6** | **rs** | **0.1903** | **10.5239** |

```
node# name   ---------- GLOBAL ---------
             Displ.x  Displ.y  Rotation
    1 S01.00  0.87699  0.03093 -0.00425
    2 S01.01  0.87698  0.01084 -0.00428
    3 S01.02  0.87698 -0.00217 -0.00441
    4 C01.01  0.85928 -0.00201 -0.00605
    5 C01.02  0.72688 -0.00147 -0.01563
    6 C01.03  0.49873 -0.00092 -0.02210
    7 C01.04  0.21194 -0.00038 -0.02546
    8 P01.01  0.15947 -0.00028 -0.02572
    9 P01.02  0.10654 -0.00019 -0.02590
   10 P01.03  0.05333 -0.00009 -0.02600
   11 P01.04  0.00000  0.00000 -0.02603
   12 S02.01  0.87699 -0.01377 -0.00332
   13 S02.02  0.87701 -0.02802 -0.00079
   14 S02.03  0.87702 -0.02622  0.00115
   15 S02.04  0.87700 -0.01502  0.00178
   16 S02.05  0.87697 -0.00605  0.00039
```

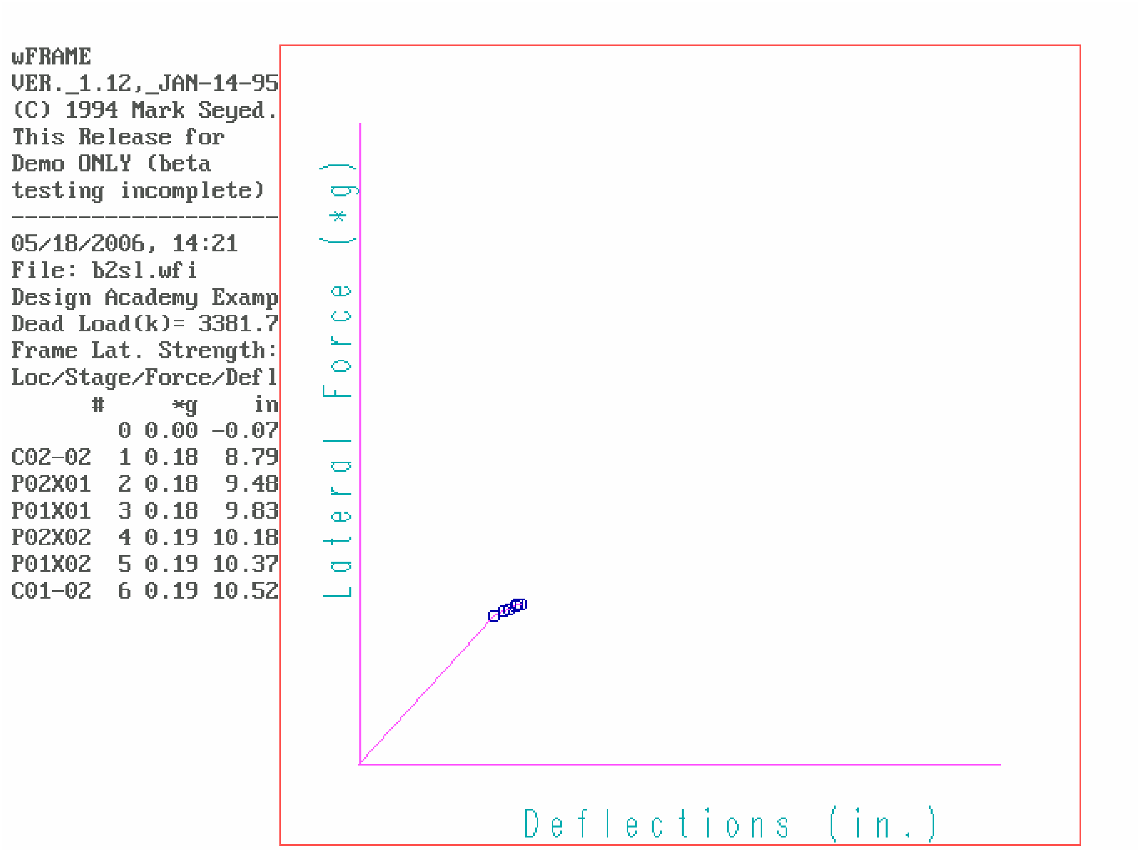
## APPENDIX – L

(*wFRAME* Output File) - Continues

```
   17 S02.06  0.87696 -0.00682 -0.00100
   18 C02.01  0.87079 -0.00634 -0.00263
   19 C02.02  0.73519 -0.00462 -0.01588
   20 C02.03  0.50407 -0.00290 -0.02235
   21 C02.04  0.21424 -0.00118 -0.02573
   22 P02.01  0.16121 -0.00089 -0.02600
   23 P02.02  0.10771 -0.00059 -0.02618
   24 P02.03  0.05392 -0.00030 -0.02628
   25 P02.04  0.00000  0.00000 -0.02631
   26 S03.01  0.87696 -0.01003 -0.00112
   27 S03.02  0.87697 -0.01545 -0.00116

element   node  -------- local -----------  ------ element ----------
#    name  fix     displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1  0.87699  0.03093 -0.00425    31.37     -0.01       0.00
                2  0.87698  0.01084 -0.00428   -31.37    322.86    -761.98
  2 S01-02 rn   2  0.87698  0.01084 -0.00428    79.93   -322.85     761.94
                3  0.87698 -0.00217 -0.00441   -79.93    528.05   -2038.30
  3 C01-01 rn   3  0.00217  0.87698 -0.00441   814.86    295.87   13637.29
                4  0.00201  0.85928 -0.00605  -814.86   -295.87 -12636.74
  4 C01-02 rs   4  0.00201  0.85928 -0.00605   814.88    295.88   12636.00
                5  0.00147  0.72688 -0.01563  -814.88   -295.88   -9106.20
  5 C01-03 rn   5  0.00147  0.72688 -0.01563   814.88    295.89    9106.22
                6  0.00092  0.49873 -0.02210  -814.88   -295.89   -5576.25
  6 C01-04 rn   6  0.00092  0.49873 -0.02210   814.88    295.88    5576.32
                7  0.00038  0.21194 -0.02546  -814.88   -295.88   -2046.37
  7 P01-01 rn   7  0.00038  0.21194 -0.02546   814.88    295.73    2047.11
                8  0.00028  0.15947 -0.02572  -814.88   -295.73   -1440.69
  8 P01-02 rn   8  0.00028  0.15947 -0.02572   814.88    275.51    1440.64
                9  0.00019  0.10654 -0.02590  -814.88   -275.51    -876.00
  9 P01-03 rn   9  0.00019  0.10654 -0.02590   814.88    231.57     876.37
               10  0.00009  0.05333 -0.02600  -814.88   -231.57    -401.75
 10 P01-04 rn  10  0.00009  0.05333 -0.02600   814.88    196.02     401.81
               11  0.00000  0.00000 -0.02603  -814.88   -196.02      -0.02
 11 S02-01 rn   3  0.87698 -0.00217 -0.00441  -176.75    286.81 -11599.76
               12  0.87699 -0.01377 -0.00332   176.75    -81.61  12152.41
 12 S02-02 rn  12  0.87699 -0.01377 -0.00332  -112.03     81.70 -12152.37
               13  0.87701 -0.02802 -0.00079   112.03    397.10  11048.49
 13 S02-03 rn  13  0.87701 -0.02802 -0.00079   -20.60   -397.10 -11048.48
               14  0.87702 -0.02622  0.00115    20.60    875.90    6593.00
 14 S02-04 rn  14  0.87702 -0.02622  0.00115    70.88   -875.90   -6593.00
               15  0.87700 -0.01502  0.00178   -70.88   1354.70   -1214.09
 15 S02-05 rn  15  0.87700 -0.01502  0.00178   162.24  -1354.70    1214.09
               16  0.87697 -0.00605  0.00039  -162.24   1833.50 -12372.80
 16 S02-06 rn  16  0.87697 -0.00605  0.00039   228.60  -1833.50  12372.78
               17  0.87696 -0.00682 -0.00100  -228.60   2038.70 -18181.08
 17 C02-01 rn  17  0.00682  0.87696 -0.00100  2566.87    349.18  16143.98
               18  0.00634  0.87079 -0.00263 -2566.87   -349.18 -14963.33
 18 C02-02 rs  18  0.00634  0.87079 -0.00634  2566.81    348.82  14964.00
               19  0.00462  0.73519 -0.01588 -2566.81   -348.82 -10802.60
 19 C02-03 rn  19  0.00462  0.73519 -0.01588  2566.81    348.82  10802.66
               20  0.00290  0.50407 -0.02235 -2566.81   -348.82   -6641.19
 20 C02-04 rn  20  0.00290  0.50407 -0.02235  2566.81    348.81    6641.24
               21  0.00118  0.21424 -0.02573 -2566.81   -348.81   -2479.92
 21 P02-01 rn  21  0.00118  0.21424 -0.02573  2566.81    348.49    2479.88
               22  0.00089  0.16121 -0.02600 -2566.81   -348.49   -1765.94
 22 P02-02 rn  22  0.00089  0.16121 -0.02600  2566.81    328.24    1765.77
               23  0.00059  0.10771 -0.02618 -2566.81   -328.24   -1092.73
 23 P02-03 rn  23  0.00059  0.10771 -0.02618  2566.81    284.77    1093.33
               24  0.00030  0.05392 -0.02628 -2566.81   -284.77    -509.41
 24 P02-04 rn  24  0.00030  0.05392 -0.02628  2566.81    248.60     509.76
               25  0.00000  0.00000 -0.02631 -2566.81   -248.60      -0.07
 25 S03-01 rn  17  0.87696 -0.00682 -0.00100   -80.75    528.17    2038.65
               26  0.87696 -0.01003 -0.00112    80.75   -322.97    -761.94
 26 S03-02 rn  26  0.87696 -0.01003 -0.00112   -31.13    322.85     761.91
               27  0.87697 -0.01545 -0.00116    31.13      0.00       0.01
```

## APPENDIX – M

(Force – Displacement Relationship)



```
05/15/2006, 15:50
Design Academy Example No: 1 (Bent 2)

*************************************************************
*                                                           *
*                       wFRAME                              *
*                                                           *
*          PUSH ANALYSIS of BRIDGE BENTS and FRAMES.        *
*                                                           *
*       Indicates formation of successive plastic hinges.   *
*                                                           *
* VER._1.12,_JAN-14-95                                      *
*                                                           *
* Copyright (C) 1994 By Mark Seyed.                         *
*                                                           *
* This program should not be distributed under any          *
* condition. This release is for demo ONLY (beta testing    *
* is not complete). The author makes no expressed or        *
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for           *
* incidental or consequential damages arising out of the    *
* use of this program.                                      *
*                                                           *
*************************************************************


Node Point Information:

Fixity condition definitions:
    s=spring and value
    r=complete release
    f=complete fixity with imposed displacement

node    name    coordinates    -----------fixity --------
  #              X       Y     X-dir.     Y-dir.   Rotation
    1 S01.00     0.00     0.00   r          r          r
    2 S01.01     4.72     0.00   r          r          r
    3 S01.02     7.72     0.00   r          r          r
    4 C01.01     7.72    -3.38   r          r          r
    5 C01.02     7.72   -15.31   r          r          r
    6 C01.03     7.72   -27.24   r          r          r
    7 C01.04     7.72   -39.17   r          r          r
    8 P01.01     7.72   -41.22   s 1.4e+002  r          r
    9 P01.02     7.72   -43.27   s 4.1e+002  r          r
   10 P01.03     7.72   -45.32   s 6.7e+002  r          r
   11 P01.04     7.72   -47.37   f 0.0000   f 0.0000   r
   12 S02.01    10.72     0.00   r          r          r
   13 S02.02    17.72     0.00   r          r          r
   14 S02.03    24.72     0.00   r          r          r
   15 S02.04    31.72     0.00   r          r          r
   16 S02.05    38.72     0.00   r          r          r
   17 S02.06    41.72     0.00   r          r          r
   18 C02.01    41.72    -3.38   r          r          r
   19 C02.02    41.72   -15.31   r          r          r
   20 C02.03    41.72   -27.24   r          r          r
   21 C02.04    41.72   -39.17   r          r          r


Cumulative Results of analysis at end of stage   6

Plastic Action at:
                       Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL= 3381.7)  /    (in)
P02X01     1      2       0.1863          9.3076
P01X01     2      2       0.1958          9.7870
P02X02     3      2       0.1966          9.8292
P01X02     4      2       0.2059         10.3036
C02-02     5     rs       0.2147         10.7599
```

# APPENDIX – N

(Cap Beam – Seismic Moment and Shear Demands) - Continues

C01-02 6 rs 0.2275 12.3779

| node# | name | ---------- GLOBAL --------- | | |
|---|---|---|---|---|
| | | Displ.x | Displ.y | Rotation |
| 1 | S01.00 | 1.03149 | 0.03456 | -0.00466 |
| 2 | S01.01 | 1.03149 | 0.01254 | -0.00469 |
| 3 | S01.02 | 1.03148 | -0.00170 | -0.00482 |
| 4 | C01.01 | 1.01183 | -0.00158 | -0.00679 |
| 5 | C01.02 | 0.85856 | -0.00115 | -0.01829 |
| 6 | C01.03 | 0.59020 | -0.00072 | -0.02608 |
| 7 | C01.04 | 0.25113 | -0.00029 | -0.03015 |
| 8 | P01.01 | 0.18897 | -0.00022 | -0.03047 |
| 9 | P01.02 | 0.12627 | -0.00015 | -0.03069 |
| 10 | P01.03 | 0.06321 | -0.00007 | -0.03081 |
| 11 | P01.04 | 0.00000 | 0.00000 | -0.03085 |
| 12 | S02.01 | 1.03150 | -0.01419 | -0.00350 |
| 13 | S02.02 | 1.03152 | -0.02840 | -0.00064 |
| 14 | S02.03 | 1.03153 | -0.02512 | 0.00137 |
| 15 | S02.04 | 1.03151 | -0.01281 | 0.00182 |
| 16 | S02.05 | 1.03148 | -0.00492 | -0.00001 |
| 17 | S02.06 | 1.03145 | -0.00729 | -0.00167 |
| 18 | C02.01 | 1.02247 | -0.00677 | -0.00363 |
| 19 | C02.02 | 0.86615 | -0.00493 | -0.01853 |
| 20 | C02.03 | 0.59507 | -0.00310 | -0.02630 |
| 21 | C02.04 | 0.25323 | -0.00126 | -0.03039 |
| 22 | P02.01 | 0.19057 | -0.00095 | -0.03072 |
| 23 | P02.02 | 0.12734 | -0.00063 | -0.03095 |
| 24 | P02.03 | 0.06376 | -0.00032 | -0.03107 |
| 25 | P02.04 | 0.00000 | 0.00000 | -0.03111 |
| 26 | S03.01 | 1.03146 | -0.01250 | -0.00179 |
| 27 | S03.02 | 1.03147 | -0.02108 | -0.00183 |

| element | | | node | -------- local ----------- | | | ------ element ---------- | | |
|---|---|---|---|---|---|---|---|---|---|
| # | name | fix | | displ.x | displ.y | rotation | axial | shear | moment |
| 1 | S01-01 | rn | 1 | 1.03149 | 0.03456 | -0.00466 | 37.40 | -0.01 | 0.01 |
| | | | 2 | 1.03149 | 0.01254 | -0.00469 | -37.40 | 322.86 | -761.98 |
| 2 | S01-02 | rn | 2 | 1.03149 | 0.01254 | -0.00469 | 95.50 | -322.85 | 761.94 |
| | | | 3 | 1.03148 | -0.00170 | -0.00482 | -95.50 | 528.05 | -2038.30 |
| 3 | C01-01 | rn | 3 | 0.00170 | 1.03148 | -0.00482 | 639.94 | 353.65 | 16359.82 |
| | | | 4 | 0.00158 | 1.01183 | -0.00679 | -639.94 | -353.65 | -15163.66 |
| 4 | C01-02 | rs | 4 | 0.00158 | 1.01183 | -0.00679 | 639.98 | 353.64 | 15163.00 |
| | | | 5 | 0.00115 | 0.85856 | -0.01829 | -639.98 | -353.64 | -10944.11 |
| 5 | C01-03 | rn | 5 | 0.00115 | 0.85856 | -0.01829 | 639.98 | 353.66 | 10944.14 |
| | | | 6 | 0.00072 | 0.59020 | -0.02608 | -639.98 | -353.66 | -6725.06 |
| 6 | C01-04 | rn | 6 | 0.00072 | 0.59020 | -0.02608 | 639.98 | 353.64 | 6725.13 |
| | | | 7 | 0.00029 | 0.25113 | -0.03015 | -639.98 | -353.64 | -2506.10 |
| 7 | P01-01 | rn | 7 | 0.00029 | 0.25113 | -0.03015 | 639.98 | 353.51 | 2506.99 |
| | | | 8 | 0.00022 | 0.18897 | -0.03047 | -639.98 | -353.51 | -1782.15 |
| 8 | P01-02 | rn | 8 | 0.00022 | 0.18897 | -0.03047 | 639.98 | 333.29 | 1782.11 |
| | | | 9 | 0.00015 | 0.12627 | -0.03069 | -639.98 | -333.29 | -1099.10 |
| 9 | P01-03 | rn | 9 | 0.00015 | 0.12627 | -0.03069 | 639.98 | 289.29 | 1099.54 |
| | | | 10 | 0.00007 | 0.06321 | -0.03081 | -639.98 | -289.29 | -506.62 |
| 10 | P01-04 | rn | 10 | 0.00007 | 0.06321 | -0.03081 | 639.98 | 247.19 | 506.68 |
| | | | 11 | 0.00000 | 0.00000 | -0.03085 | -639.98 | -247.19 | 0.00 |
| 11 | S02-01 | rn | 3 | 1.03148 | -0.00170 | -0.00482 | -211.27 | 111.89 | -14322.39 |
| | | | 12 | 1.03150 | -0.01419 | -0.00350 | 211.27 | 93.31 | **14350.28** |
| 12 | S02-02 | rn | 12 | 1.03150 | -0.01419 | -0.00350 | -133.82 | -93.18 | -14350.24 |
| | | | 13 | 1.03152 | -0.02840 | -0.00064 | 133.82 | 571.98 | 12022.15 |
| 13 | S02-03 | rn | 13 | 1.03152 | -0.02840 | -0.00064 | -24.49 | -571.98 | -12022.14 |
| | | | 14 | 1.03153 | -0.02512 | 0.00137 | 24.49 | 1050.78 | 6342.45 |
| 14 | S02-04 | rn | 14 | 1.03153 | -0.02512 | 0.00137 | 84.84 | -1050.79 | -6342.45 |
| | | | 15 | 1.03151 | -0.01281 | 0.00182 | -84.84 | 1529.59 | -2688.86 |
| 15 | S02-05 | rn | 15 | 1.03151 | -0.01281 | 0.00182 | 194.14 | -1529.59 | 2688.86 |
| | | | 16 | 1.03148 | -0.00492 | -0.00001 | -194.14 | 2008.39 | -15071.78 |
| 16 | S02-06 | rn | 16 | 1.03148 | -0.00492 | -0.00001 | 273.35 | -2008.39 | **15071.76** |
| | | | 17 | 1.03145 | -0.00729 | -0.00167 | -273.35 | 2213.59 | -21404.73 |
| 17 | C02-01 | rn | 17 | 0.00729 | 1.03145 | -0.00167 | 2741.74 | 417.33 | 19367.77 |
| | | | 18 | 0.00677 | 1.02247 | -0.00363 | -2741.74 | -417.33 | -17956.42 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 18 | C02-02 | rs | 18 | 0.00677 | 1.02247 | -0.00706 | 2741.69 | 417.18 | 17957.00 |
| | | | 19 | 0.00493 | 0.86615 | -0.01853 | -2741.69 | -417.18 | -12980.05 |
| 19 | C02-03 | rn | 19 | 0.00493 | 0.86615 | -0.01853 | 2741.69 | 417.18 | 12980.12 |
| | | | 20 | 0.00310 | 0.59507 | -0.02630 | -2741.69 | -417.18 | -8003.12 |
| 20 | C02-04 | rn | 20 | 0.00310 | 0.59507 | -0.02630 | 2741.69 | 417.17 | 8003.17 |
| | | | 21 | 0.00126 | 0.25323 | -0.03039 | -2741.69 | -417.17 | -3026.31 |
| 21 | P02-01 | rn | 21 | 0.00126 | 0.25323 | -0.03039 | 2741.69 | 416.81 | 3026.30 |
| | | | 22 | 0.00095 | 0.19057 | -0.03072 | -2741.69 | -416.81 | -2172.40 |
| 22 | P02-02 | rn | 22 | 0.00095 | 0.19057 | -0.03072 | 2741.69 | 396.55 | 2172.30 |
| | | | 23 | 0.00063 | 0.12734 | -0.03095 | -2741.69 | -396.55 | -1359.19 |
| 23 | P02-03 | rn | 23 | 0.00063 | 0.12734 | -0.03095 | 2741.69 | 353.00 | 1359.84 |
| | | | 24 | 0.00032 | 0.06376 | -0.03107 | -2741.69 | -353.00 | -635.98 |
| 24 | P02-04 | rn | 24 | 0.00032 | 0.06376 | -0.03107 | 2741.69 | 310.33 | 636.35 |
| | | | 25 | 0.00000 | 0.00000 | -0.03111 | -2741.69 | -310.33 | -0.06 |
| 25 | S03-01 | rn | 17 | 1.03145 | -0.00729 | -0.00167 | -96.61 | 528.16 | 2038.61 |
| | | | 26 | 1.03146 | -0.01250 | -0.00179 | 96.61 | -322.96 | -761.93 |
| 26 | S03-02 | rn | 26 | 1.03146 | -0.01250 | -0.00179 | -37.19 | 322.85 | 761.91 |
| | | | 27 | 1.03147 | -0.02108 | -0.00183 | 37.19 | 0.00 | 0.01 |

# APPENDIX – O

(Joint Movement Calculations)

STATE OF CALIFORNIA.DEPARTMENT OF TRANSPORTATION

**JOINT MOVEMENTS CALCULATIONS** [a]

DS-D-0129(Rev.5/93)

**Note:** Specific instructions are included as footnotes.

| EA | DISTRICT | COUNTY | ROUTE | PM (KP) | BRIDGE NAME AND NUMBER |
|---|---|---|---|---|---|
| 910076 | 59 | ES | 999 | 99 | Prototype Bridge |

| TYPE OF STRUCTURE | TYPE ABUTMENT | TYPE EXPANSION(2" elasto pads, etc.) |
|---|---|---|
| CIP/PS BOX GIRDER | Seat | Elastomeric Bearing Pads |

| (1) TEMPERATURE EXTREMES(from Preliminary Rerport) | | | | | (2)THERMAL MOVEMENT (inches/100 feet) | | ANTICIPATED SHORTENING (inches/100 feet) | | | (3)MOVEMENT FACTOR (inches/100 feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Type Of Structure** | | | | | | | | |
| MAXIMUM | 110 ? | Steel | Range( | ? )(0.0000065X1200) = | | + | 0 | | = | |
| - MINIMUM | 23 ? | Concrete (Conventional) | Range( | ? )(0.0000060X1200) = | | + | 0.06 | | = | |
| | | Concrete(Pretensioned) | Range( | ? )(0.0000060X1200) = | | + | 0.12 | g | = | |
| = Range | 87 ? | Concrete(Post Tensioned) | Range( | 87 ? )(0.0000060X1200) = | 0.6264 | + | 0.63 | g | = | 1.26 |

| ITEM(1) DESIGNER | DATE | ITEM(2)CHECKED BY | DATE |
|---|---|---|---|
| DESIGNER | | CHECKER | 5/2/2006 |

| To be filled in by Office of Structures Design [b] | | | | | | To be filled in by SR [c] | | | | | Date: |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Seal Width Limits [d] | | | Groove (saw cut) Width or Installation Width [e] | | |
| Location | Skew (degrees) Do not use in calculation | (4) Contributing Length (feet) | Calculated Movement (inches) (3)X(4)/100 | M.R. (inches) (Round up to 1/2") | Seal Type A,B, (Others) or Open Joint | Catalog Number | W1 (inches) Maximum | (5) W2 (inches) Min.@Max. Temperature | Structure Temperature ( ? ) [f] | (6)Adjust from Maximum Temp. (inches) Δ°/(1)X(2)X(4)/100 | Width at Temp. Listed (inches) w=(5)+(6) |
| Abut 1 | 0 | 202 | 2.53 | 2.50 | Joint Seal Assembly(strip seal) | | | | | | |
| Abut 4 | 0 | 210 | 2.64 | 3.00 | Joint Seal Assembly(strip seal) | | | | | | |
| | | | | | **see XS-12-59** | | | | | | |

$$\text{Anticipated Shortening} = \frac{0.63}{100} \times \left( \frac{202 + 210}{2} \right) = 1.30\ in$$

## APPENDIX – P

(wFRAME Longitudinal Push Over – Input file)

```
wFPREP
VER._1.12,_JAN-14-95
JOB_TITLE
Design Academy Example No: 1 (Superstructure right Push)
*********************************************************************
* Columns are pinned at the base. Column longitudinal reinforcement *
* consists of 26, #14 bars. The lateral reinforcement consists of   *
* #8 Hoops at 5" spacing. The superstructure properties used are as *
* calculated in BDS.                                                *
*                                                                   *
*                                                    05/23/06       *
*********************************************************************
All units in kips and feet
******************************************************************
            ***  Analysis Control Block Info ***

The following block of information is for analysis control.
Number of spans and number of link beams are specified.
Direction of push is specified (push to left is not checked yet).
2nd deck out-of-phase push is not checked yet.
******************************************************************
ANALYSIS_CONTROL
    NUMBER_OF_SPANS     5
    NUMBER_OF_LINK_BEAMS   0
    DIRECTION_OF_PUSH       right
    2ND_DECK_OUT_OF_PHASE   no
******************************************************************
            ***  Structural Data Block Info ***

The follwing block of information is for definition of spans, columns
and piles.  A span/column/pile code and number (example S01) is specified;
followed by total number of elements in span/col/pile; followed by number
of different types of segments over which all elements are defined. The logic
of this version is such that info for S01, C01, P01, S02, C02 P02, etc...
is expected in the specified order. If a column is connected to a pile cap
and a pile group and the user does not wish to model the pile group, then
the portion of the column below ground (usually 2') must be modeled as a pile
and the tip of the 2' pile should be modeled as fixed in X and Y translation
and fixed, partially released (spring), or completely released for moment
for a column to footing connection of pin nature.51.84

For each segment input the following:
Number of elements per segment;
Fixity code (rn= no release, rs=release start, re=release end);
Length of each element (L);
Depth of element in direction of bending (not used in this version);
Area of cross section;
Modulus of elasticity (Ei);
Softened modulus (Ef, not used in this version);
Cracked moment of inertia(Icr);
Uniform dead load q (negative for superstructure elements, zero otherwise);
Positive plastic moment capacity (Mpp);
Negative plastic moment capacity (Mpn);
Tolerance for elasto-plastic transition (.02 recommended);
Element status = e for elastic, i for inactive.

#   F   L    D      A      Ei     Ef     I     q      Mp    Mn      T  status
*****************************************************************************
STRUCTURAL_DATA
S01 1 1
 1  rn  2.0  6.75 103.49 629528  62953 826.75  -0.01   83028  83028    0.02 e
C01   1  1
 1  rs  1.0  6.00  56.55 629528  62953  94.88     0    83028  83028    0.02 e
P01   1  1
 1  rn  1.0  6.00  56.55 629528  62953  47.44     0    27676  27676    0.02 e
S02   12  4
```

```
 9  rn 12.60 6.75 103.49 629528  62953 731.10 -18.25   83028  83028    0.02 e
 1  rn  4.17 6.75 109.55 629528  62953 778.93 -19.12   83028  83028    0.02 e
 1  rn  4.17 6.75 109.55 629528  62953 778.93 -19.59   83028  83028    0.02 e
 1  rn  4.26 6.75 115.60 629528  62953 826.75 -70.07   83028  83028    0.02 e
C02   4  2
 1  rn  3.38 6.00  56.55 629528  62953  94.88     0    83028  83028    0.02 e
 3  rn 11.93 6.00  56.55 629528  62953  47.44     0    27676  27676    0.02 e
P02   4  2
 3  rn  2.05 6.00  56.55 629528  62953  47.44     0    27676  27676    0.02 e
 1  rn  2.05 6.00  56.55 629528  62953  47.44     0    27676  27676    0.02 e
S03  14  5
 1  rn  4.26 6.75 115.60 629528  62953 826.75 -70.07   83028  83028    0.02 e
 2  rn  6.27 6.75 109.55 629528  62953 778.93 -18.64   83028  83028    0.02 e
 8  rn 16.80 6.75 103.49 629528  62953 731.10 -18.25   83028  83028    0.02 e
 2  rn  6.27 6.75 109.55 629528  62953 778.93 -18.64   83028  83028    0.02 e
 1  rn  4.26 6.75 115.60 629528  62953 826.75 -70.07   83028  83028    0.02 e
C03   4  2
 1  rn  3.38 6.00  56.55 629528  62953  94.44     0    83028  83028    0.02 e
 3  rn 11.95 6.00  56.55 629528  62953  47.22     0    27554  27554    0.02 e
P03   5  2
 4  rn  2.23 6.00  56.55 629528  62953  47.22     0    27554  27554    0.02 e
 1  rn  2.23 6.00  56.55 629528  62953  47.22     0    27554  27554    0.02 e
S04  12   4
 1  rn  4.26 6.75 115.60 629528  62953 826.75 -70.07   83028  83028    0.02 e
 1  rn  3.77 6.75 109.55 629528  62953 778.93 -19.64   83028  83028    0.02 e
 1  rn  3.77 6.75 109.55 629528  62953 778.93 -19.21   83028  83028    0.02 e
 9  rn 11.80 6.75 103.49 629528  62953 731.10 -18.25   83028  83028    0.02 e
C04   1  1
 1  rs  1.0  6.00  56.55 629528  62953  94.44     0    83028  83028    0.02 e
P04   1  1
 1  rn  1.0  6.00  56.55 629528  62953  47.22     0    27554  27554    0.02 e
S05 1 1
 1  rn  2.0  6.75 103.49 629528  62953 826.75  -0.01   83028  83028    0.02 e
*******************************************************************************

                ***  Link Beam or Second Deck Block Info ***

Link beam or second deck option may be placed at any span or any
elevation relative to the superstructure (down is negative).

For each link beam indicate beam number; total number of elements;
nmber of segments; left end elevation; right end elevation.

For each link beam segment input the following:

        see Structural Data Block Info.

Data Specific to this bridge: Link Beams are NOT being used.
#   F   L    D      A      Ei     Ef     I     q      Mp    Mn      T  status
******************************************************************
LINK_BEAM_DATA
******************************************************************

                ***  Soil p-y Block Info ***

This section contains the p-y information. First the number of p-y curves
is specified in the analysis (max 50). Then For each p-y curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), p1, y1, p2, y2.
Data Specific to this bridge:

There are two layers of sand.
The top layer is loose sand with layer thickness of 3'.
The bottom layer is medimum dense sand with layer thickness of 5'
Two p-y curves are used per layer.
*****************************************************************
PYS
NUMBER_OF_PYS   8
```

```
PY_NO.  NO._OF_SEGMENTS     P1        Y1       P2        Y2
  1     2           5.040     0.142   5.040     1.000
  2     2          28.800     0.154  28.800     1.000
  3     2          31.680     0.104  31.680     1.000
  4     2          95.360     0.108  95.360     1.000
  5     2           5.040     0.138   5.040     1.000
  6     2          28.800     0.154  28.800     1.000
  7     2          30.960     0.110  30.960     1.000
  8     2         126.240     0.108 126.240     1.000
******************************************************************

                ***  Soil t-z Block Info ***

This section contains the t-z information. First the number of t-z curves
is specified in the analysis (max 50). Then For each t-z curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), t1, z1, t2, z2.

t-z curves are usually specified for muti-pile situation.

Data Specific to this bridge:
Curve 1 is applicable at 6" below Ground Level
Curve 2 is applicable at 2'-6" below Ground Level.
Curve 3 is applicable at 3'-6" below Ground Level.
Curve 4 is applicable at 7'-6" below Ground Level.
******************************************************************
TZS
NUMBER_OF_TZS   0
TZ_NO.  NO._OF_SEGMENTS     T1      Z1      T2      Z2
******************************************************************

                ***  Foundation Block Info for p-y application  ***

These p-y values are used to attach horizontal springs to the pile
nodes for lateral response of the pile in the soil-structure interaction
study.

This section contains the foundation information for the p-y applications.
A foundation location is defined as pile locations defined in the structural
input. As discussed earlier the portion of a column below ground is called
a pile.

For each foundation location (i.e. pile or column 1, 2, etc.) indicate:
location number; and the number of p-y applications.

Each soil layer is considered one p-y application in this example.
A soil layer may be subdivided into several segments, each considered
one application. You need to input one new line per each count of
application. Provide as many new lines as the number of
p-y applications with the following info:
Start & end depth of soil layer or sub-layer (measured from top of pile).
Starting p-y number at top of layer. End p-y number at bottom of layer
where linear interpolation is used for the generation of the intermediate
springs.

A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME. Also the group reduction factors
typically used in soil-structure interaction problems for pile-groups may
be applied through this factor.

Data Specific to this bridge:

******************************************************************
FOUNDATIONS_PY
   |   NO. OF     |         |       |           |          | FACTOR
LOC| SOIL-LAYERS/ |START    |END    |START-PY   |END-PY   |FOR # OF
NO.| PY APPLIC.   |DEPTH    |DEPTH |  NO.      |   NO.   |  PILE
1                                   0
```

```
2       2
                    0.00     3.28    1          2        1
                    3.28     8.20    3          4        1
3       2
                    0.00    3.28     5          6        1
                    3.28   11.15     7          8        1
4       0

*******************************************************************

                ***  Foundation Block Info for t-z application  ***

This section contains the foundation information for the t-z applications.
The general logic followed in this section is similar to the p-y
applications. These values are used to attach vertical springs to the pile
nodes for axial response of the pile in the soil-structure interaction
study.

For each foundation location (i.e. column 1, 2, etc.) indicate:
location number, and the number of t-z applications.
Each soil layer may be considered one t-z application or
a soil layer may be subdivided into several segments, each considered
one application. Provide as many new lines as the number of
t-z applications with the following info:
start & end depth of soil (measured from top of pile). Starting t-z number
at top of layer. End t-z number at bottom of layer where linear interpolation
is used for the generation of the intermediate springs.
A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME.

Data Specific to this bridge: None

*******************************************************************
FOUNDATIONS_TZ
   |   NO. OF     |         |      |           |         | FACTOR
LOC| SOIL-LAYERS/ |START    |END   |START-TZ  |END-TZ  |FOR # OF
NO.| TZ APPLIC.   |DEPTH    |DEPTH |  NO.      |   NO.  |  PILES
1       0
2       0
3       0
4       0
*******************************************************************

        ***  Boundary node Block Info for spring application  ***

This section contains the boundary information where additional springs
may be attached to the extreme boundaries of the structure. The locations
are at the pile tips and at the abutments.

The boundary locations are identified according to the structural definition
listed earlier in the input file. The following possibilities exist:

For transverse analysis of say a 2 column bent (pin at base of columns) on
pile group the following assumptions may be made if the user does not wish
to model the piles explicitly. The pile group at each footing location may
be modeled as providing fixity or spring action in horizontal direction (the
user must estimate the spring value, otherwise fixity must be used).
Therefore, boundary locations 0 and 3 are the overhangs and they must be
released in all components (rx, ry, rz). The locations 1 and 2 will be modeld
at column to footing connection as fx, fy, rz. In general for the transverse
analysis of bents with "n" columns, locationns 1 and n+1 indicate the ends
of cap beam and it usually is free (rx, ry, rz).

For the transverse analysis of the above bent the user may decide to model
the entire pile groups at the two foundations. The piles must be numbered as
seen on the elevation view of the bent. This example will be presented later
```

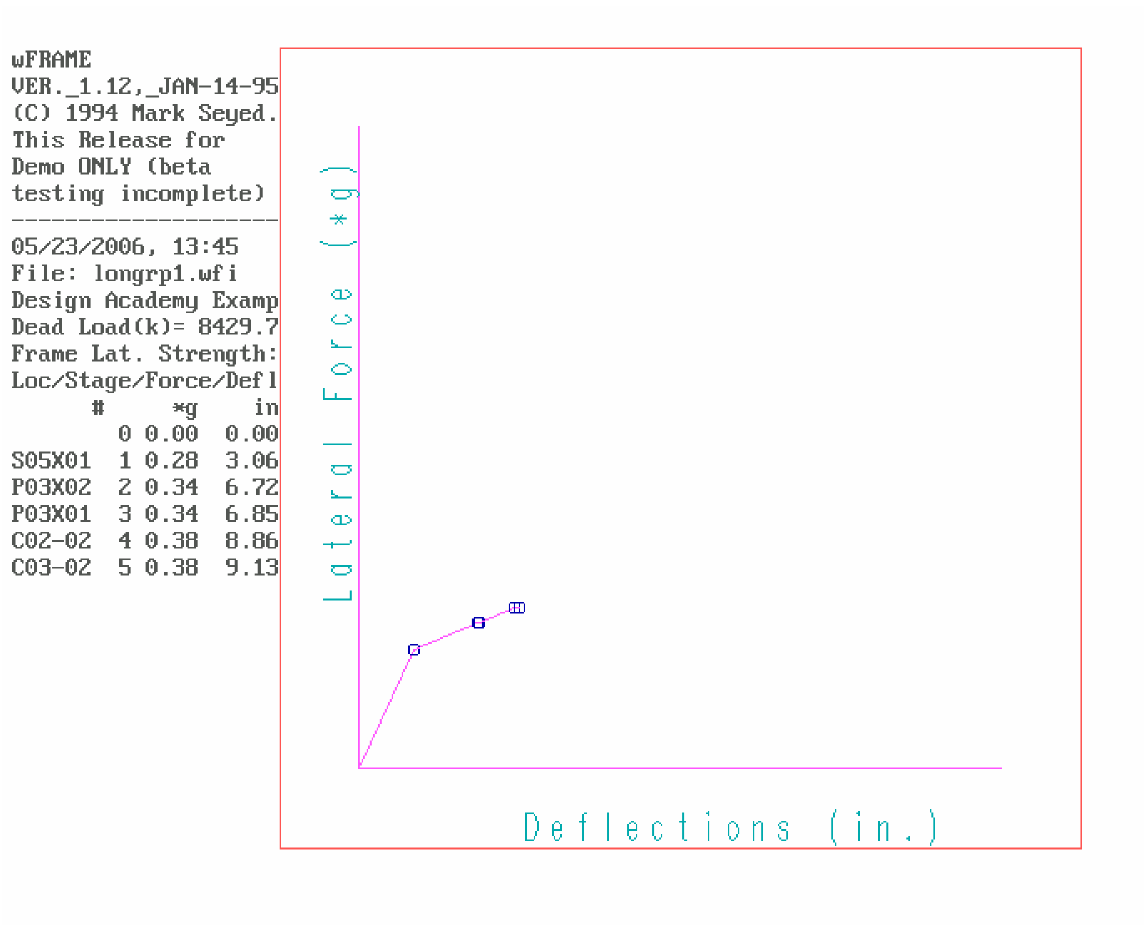
due to the complexity of the situation.

```
For the longitudinal analysis of a 2 span bridge one may input two ficticious
column/pile combinations at the abutments with proper releases to model the
roller action of the seat abutment support. In this case release the top of
the ficticious column for moment (rs in the element) and model the bottom
with fx, fy, rz. This column will not carry a shear in the longitudinal push
and it will only carry the dead load at the abutment. Attach a spring at the
right abutment to model the passive resistance of the soil (sx plus a new
line with k1, del1, k2, del2).

For Location: enter 0 for left end of frame, 1 to xx for tips of piles,
and the last location is for right end of frame.
After boundary location number enter the following info on the next line:
Fixity code for each X, Y and Z directions on consecutive lines:
(rx=release x dir., fx=fix x dir., sx=spring code in x dir. etc.).
If a spring is defined, the next line must be included for the spring
with the following info.:
Number of segments, stiffness and displacements
at breakpoints of the multi-linear curve ((ki,deli) for i=1, 2...)
(Input only 2 segments for this version with the plateaue segment
generated by computer as the third segment).
End bearing at tip of compression piles may be modeled with these springs.

Data Specific to this bridge:

For this simple example only fixity in the Y-direction is provided because
the t-z(s) were not explicitly modeled. With t-z modeling the structure will
be floating is soil with releases at all boundary locations to represent the
real condition.

******************************************************************
BOUNDARIES
LOCATION    FIXITY_CODE   NO._OF_SEGMENTS       ki       del1     k2    del2
    0
                rx
                ry
                rz
    1
                fx
                fy
                rz
    2
                fx
                fy
                rz
    3
                fx
                fy
                rz
    4
                fx
                fy
                rz
    5
                sx
                   2   7716  0.249  0.01  1
                ry
                rz
******************************************************************
```

Initial Abutment Stiffness
Units: kip,ft.

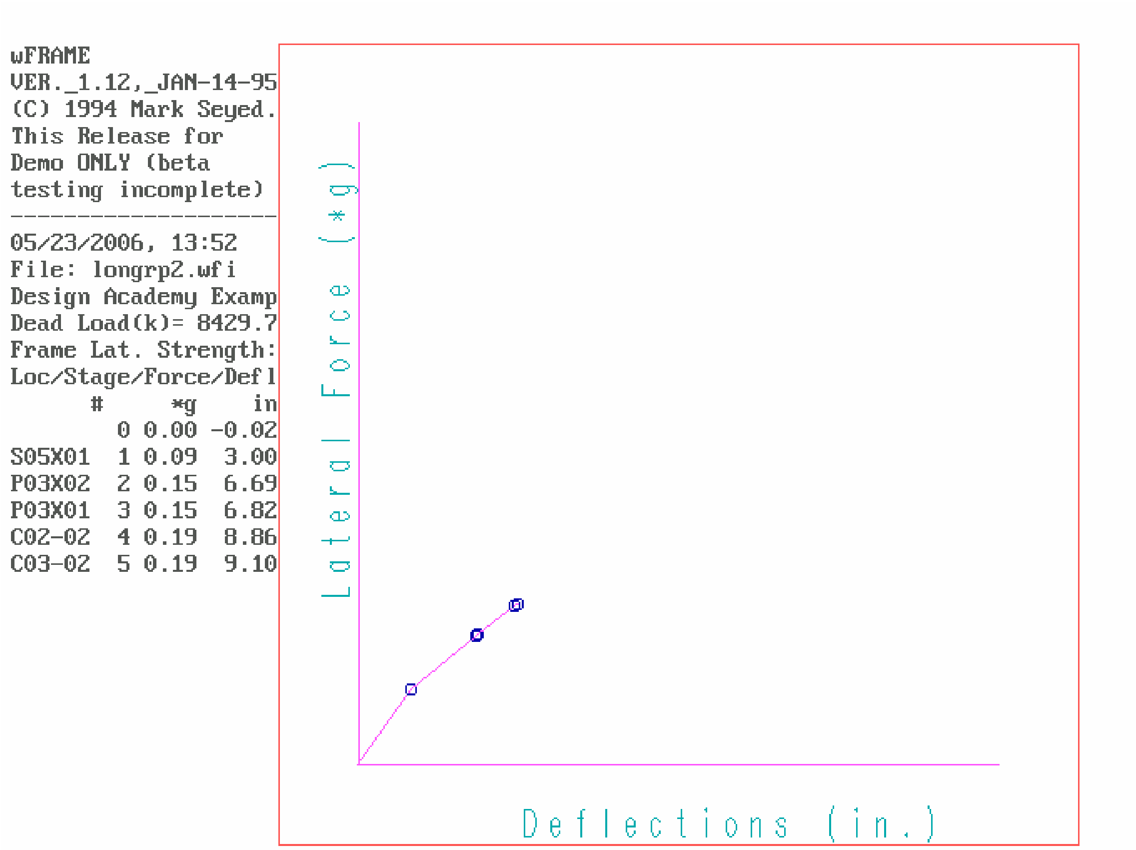
**APPENDIX – Q1**

(wFRAME Longitudinal Push Over – Force/Displacement Relationship)



## APPENDIX – Q2

(wFRAME Longitudinal Push Over – Force/Displacement Relationship)



**APPENDIX – R**

```
(wFRAME Input File – To Determine Superstructure Force due to Column Hinging, Case 1)
wFPREP
VER._1.12,_JAN-14-95
JOB_TITLE
Design Academy Example No: 1 (Superstructure Right Push)
*********************************************************************
* Columns are pinned at the base. Column longitudinal reinforcement *
* consists of 26, #14 bars. The lateral reinforcement consists of   *
* #8 Hoops at 5" spacing. The superstructure properties used are as *
* calculated in CTBridge.  This file determines the distribution of *
* the earthquake moments to the superstructure.                     *
*                                                                   *
*                                                    05/08/06       *
*********************************************************************
All units in kips and feet
******************************************************************
            ***  Analysis Control Block Info ***

The following block of information is for analysis control.
Number of spans and number of link beams are specified.
Direction of push is specified (push to left is not checked yet).
2nd deck out-of-phase push is not checked yet.
******************************************************************
ANALYSIS_CONTROL
    NUMBER_OF_SPANS     5
    NUMBER_OF_LINK_BEAMS   0
    DIRECTION_OF_PUSH       right
    2ND_DECK_OUT_OF_PHASE   no
******************************************************************
            ***  Structural Data Block Info ***

The follwing block of information is for definition of spans, columns
and piles.  A span/column/pile code and number (example S01) is specified;
followed by total number of elements in span/col/pile; followed by number
of different types of segments over which all elements are defined. The logic
of this version is such that info for S01, C01, P01, S02, C02 P02, etc...
is expected in the specified order. If a column is connected to a pile cap
and a pile group and the user does not wish to model the pile group, then
the portion of the column below ground (usually 2') must be modeled as a pile
and the tip of the 2' pile should be modeled as fixed in X and Y translation
and fixed, partially released (spring), or completely released for moment
for a column to footing connection of pin nature.51.84

For each segment input the following:
Number of elements per segment;
Fixity code (rn= no release, rs=release start, re=release end);
Length of each element (L);
Depth of element in direction of bending (not used in this version);
Area of cross section;
Modulus of elasticity (Ei);
Softened modulus (Ef, not used in this version);
Cracked moment of inertia(Icr);
Uniform dead load q (negative for superstructure elements, zero otherwise);
Positive plastic moment capacity (Mpp);
Negative plastic moment capacity (Mpn);
Tolerance for elasto-plastic transition (.02 recommended);
Element status = e for elastic, i for inactive.

#   F   L    D      A      Ei     Ef     I     q      Mpp    Mpn      T  status
*******************************************************************************
STRUCTURAL_DATA
S01 1 1
 1  rn  2.0  6.75 103.49 629528  60480 826.75     -0.01    99999  99999    0.02 e
C01   1  1
 1  rs  1.0  6.00  56.55 629528  62107  94.88     0    99999  99999    0.02 e
P01   1  1
 1  rn  1.0  6.00  56.55 629528  62107  47.44     0    99999  99999    0.02 e
S02   13  4
10  rn 10.57 6.75 103.49 629528  60480 731.10     -0.01    99999  99999    0.02 e
 1  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
```

```
 1  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
 1  rn  4.26 6.75 115.60 629528  60480 826.75     -0.01    99999  99999    0.02 e
C02   4  2
 1  rn  3.38 6.00  56.55 629528  62107  94.88     0    99999  99999    0.02 e
 3  rn 11.93 6.00  56.55 629528  62107  47.44     0    32060  34566    0.02 e
P02   4  2
 3  rn  2.05 6.00  56.55 629528  62107  47.44     0    32060  34566    0.02 e
 1  re  2.05 6.00  56.55 629528  62107  47.44     0    32060  34566    0.02 e
S03  16  5
 1  rn  4.26 6.75 115.60 629528  60480 826.75     -0.01    99999  99999    0.02 e
 2  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
10  rn 12.75 6.75 103.49 629528  60480 731.10     -0.01    99999  99999    0.02 e
 2  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
 1  rn  4.26 6.75 115.60 629528  60480 826.75     -0.01    99999  99999    0.02 e
C03   4  2
 1  rn  3.38 6.00  56.55 629528  62107  94.44     0    99999  99999    0.02 e
 3  rn 11.95 6.00  56.55 629528  62107  47.22     0    34512  31835    0.02 e
P03   5  2
 4  rn  2.23 6.00  56.55 629528  62107  47.22     0    34512  31835    0.02 e
 1  re  2.23 6.00  56.55 629528  62107  47.22     0    34512  31835    0.02 e
S04  13   4
 1  rn  4.26 6.75 115.60 629528  60480 826.75     -0.01    99999  99999    0.02 e
 1  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
 1  rn  8.00 6.75 109.55 629528  60480 778.93     -0.01    99999  99999    0.02 e
10  rn  9.77 6.75 103.49 629528  60480 731.10     -0.01    99999  99999    0.02 e
C04   1  1
 1  rs  1.0  6.00  56.55 629528  62107  94.44     0    99999  99999    0.02 e
P04   1  1
 1  rn  1.0  6.00  56.55 629528  62107  47.22     0    99999  99999    0.02 e
S05 1 1
 1  rn  2.0  6.75 103.49 629528  60480 826.75     -0.01    99999  99999    0.02 e
******************************************************************************

                *** Link Beam or Second Deck Block Info ***

Link beam or second deck option may be placed at any span or any
elevation relative to the superstructure (down is negative).

For each link beam indicate beam number; total number of elements;
nmber of segments; left end elevation; right end elevation.

For each link beam segment input the following:

        see Structural Data Block Info.

Data Specific to this bridge: Link Beams are NOT being used.
#   F   L    D      A      Ei     Ef     I     q      Mp    Mn      T  status
******************************************************************
LINK_BEAM_DATA
******************************************************************

                *** Soil p-y Block Info ***

This section contains the p-y information. First the number of p-y curves
is specified in the analysis (max 50). Then For each p-y curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), p1, y1, p2, y2.
Data Specific to this bridge:

There are two layers of sand.
The top layer is loose sand with layer thickness of 3'.
The bottom layer is medimum dense sand with layer thickness of 5'
Two p-y curves are used per layer.
*****************************************************************
PYS
NUMBER_OF_PYS   8
PY_NO.  NO._OF_SEGMENTS     P1       Y1       P2        Y2
  1         2            5.040     0.142   5.040     1.000
```

```
  2         2          28.800     0.154  28.800     1.000
  3         2          31.680     0.104  31.680     1.000
  4         2          95.360     0.108  95.360     1.000
  5         2           5.040     0.138   5.040     1.000
  6         2          28.800     0.154  28.800     1.000
  7         2          30.960     0.110  30.960     1.000
  8         2         126.240     0.108 126.240     1.000
*******************************************************************

                ***  Soil t-z Block Info ***

This section contains the t-z information. First the number of t-z curves
is specified in the analysis (max 50). Then For each t-z curve enter the
curve number, number of segments (2 for this version with the plateaue
as the third segment generated by computer), t1, z1, t2, z2.

t-z curves are usually specified for muti-pile situation.

Data Specific to this bridge:
Curve 1 is applicable at 6" below Ground Level
Curve 2 is applicable at 2'-6" below Ground Level.
Curve 3 is applicable at 3'-6" below Ground Level.
Curve 4 is applicable at 7'-6" below Ground Level.
*******************************************************************
TZS
NUMBER_OF_TZS   0
TZ_NO.  NO._OF_SEGMENTS     T1      Z1      T2      Z2
*******************************************************************

                ***  Foundation Block Info for p-y application  ***

These p-y values are used to attach horizontal springs to the pile
nodes for lateral response of the pile in the soil-structure interaction
study.

This section contains the foundation information for the p-y applications.
A foundation location is defined as pile locations defined in the structural
input. As discussed earlier the portion of a column below ground is called
a pile.

For each foundation location (i.e. pile or column 1, 2, etc.) indicate:
location number; and the number of p-y applications.

Each soil layer is considered one p-y application in this example.
A soil layer may be subdivided into several segments, each considered
one application. You need to input one new line per each count of
application. Provide as many new lines as the number of
p-y applications with the following info:
Start & end depth of soil layer or sub-layer (measured from top of pile).
Starting p-y number at top of layer. End p-y number at bottom of layer
where linear interpolation is used for the generation of the intermediate
springs.

A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME. Also the group reduction factors
typically used in soil-structure interaction problems for pile-groups may
be applied through this factor.

Data Specific to this bridge:

*******************************************************************
FOUNDATIONS_PY
   |   NO. OF     |         |       |          |         | FACTOR
LOC| SOIL-LAYERS/ |START    |END    |START-PY  |END-PY   |FOR # OF
NO.| PY APPLIC.   |DEPTH    |DEPTH  |  NO.     |   NO.   |  PILE
1       0
2        2
                     0.00     3.28    1          2        1
```

```
                     3.28     8.20    3          4        1
3       2
                     0.00    3.28     5          6        1
                     3.28   11.15     7          8        1
4       0

******************************************************************

                *** Foundation Block Info for t-z application ***

This section contains the foundation information for the t-z applications.
The general logic followed in this section is similar to the p-y
applications. These values are used to attach vertical springs to the pile
nodes for axial response of the pile in the soil-structure interaction
study.

For each foundation location (i.e. column 1, 2, etc.) indicate:
location number, and the number of t-z applications.
Each soil layer may be considered one t-z application or
a soil layer may be subdivided into several segments, each considered
one application. Provide as many new lines as the number of
t-z applications with the following info:
start & end depth of soil (measured from top of pile). Starting t-z number
at top of layer. End t-z number at bottom of layer where linear interpolation
is used for the generation of the intermediate springs.
A factor is also used for the case of many actual piles represented by one
"model pile" in the 2-D modeling of wFRAME.

Data Specific to this bridge: None

******************************************************************
FOUNDATIONS_TZ
   |   NO. OF     |         |        |           |          | FACTOR
LOC| SOIL-LAYERS/ |START    |END     |START-TZ   |END-TZ    |FOR # OF
NO.| TZ APPLIC.   |DEPTH    |DEPTH   |  NO.      |   NO.    |  PILES
1       0
2       0
3       0
4       0
******************************************************************

        *** Boundary node Block Info for spring application ***

This section contains the boundary information where additional springs
may be attached to the extreme boundaries of the structure. The locations
are at the pile tips and at the abutments.

The boundary locations are identified according to the structural definition
listed earlier in the input file. The following possibilities exist:

For transverse analysis of say a 2 column bent (pin at base of columns) on
pile group the following assumptions may be made if the user does not wish
to model the piles explicitly. The pile group at each footing location may
be modeled as providing fixity or spring action in horizontal direction (the
user must estimate the spring value, otherwise fixity must be used).
Therefore, boundary locations 0 and 3 are the overhangs and they must be
released in all components (rx, ry, rz). The locations 1 and 2 will be modeld
at column to footing connection as fx, fy, rz. In general for the transverse
analysis of bents with "n" columns, locationns 1 and n+1 indicate the ends
of cap beam and it usually is free (rx, ry, rz).


For the transverse analysis of the above bent the user may decide to model
the entire pile groups at the two foundations. The piles must be numbered as
seen on the elevation view of the bent. This example will be presented later
due to the complexity of the situation.

For the longitudinal analysis of a 2 span bridge one may input two ficticious
```

```
column/pile combinations at the abutments with proper releases to model the
roller action of the seat abutment support. In this case release the top of
the ficticious column for moment (rs in the element) and model the bottom
with fx, fy, rz. This column will not carry a shear in the longitudinal push
and it will only carry the dead load at the abutment. Attach a spring at the
right abutment to model the passive resistance of the soil (sx plus a new
line with k1, del1, k2, del2).

For Location: enter 0 for left end of frame, 1 to xx for tips of piles,
and the last location is for right end of frame.
After boundary location number enter the following info on the next line:
Fixity code for each X, Y and Z directions on consecutive lines:
(rx=release x dir., fx=fix x dir., sx=spring code in x dir. etc.).
If a spring is defined, the next line must be included for the spring
with the following info.:
Number of segments, stiffness and displacements
at breakpoints of the multi-linear curve ((ki,deli) for i=1, 2...)
(Input only 2 segments for this version with the plateaue segment
generated by computer as the third segment).
End bearing at tip of compression piles may be modeled with these springs.

Data Specific to this bridge:

For this simple example only fixity in the Y-direction is provided because
the t-z(s) were not explicitly modeled. With t-z modeling the structure will
be floating is soil with releases at all boundary locations to represent the
real condition.

******************************************************************
BOUNDARIES
LOCATION    FIXITY_CODE   NO._OF_SEGMENTS       ki       del1     k2    del2
    0
                rx
                ry
                rz
    1
                fx
                fy
                rz
    2
                fx
                fy
                rz
    3
                fx
                fy
                rz
    4
                fx
                fy
                rz
    5
                sx
                   2   7723  0.249  0  1
                ry
                rz
******************************************************************
```

```
05/08/2006, 14:34
Design Academy Example No: 1 (Superstructure Right Push)

************************************************************
*                                                          *
*                       wFRAME                             *
*                                                          *
*          PUSH ANALYSIS of BRIDGE BENTS and FRAMES.       *
*                                                          *
*       Indicates formation of successive plastic hinges.  *
*                                                          *
* VER._1.12,_JAN-14-95                                     *
*                                                          *
* Copyright (C) 1994 By Mark Seyed.                        *
*                                                          *
* This program should not be distributed under any         *
* condition. This release is for demo ONLY (beta testing   *
* is not complete). The author makes no expressed or       *
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for          *
* incidental or consequential damages arising out of the   *
* use of this program.                                     *
*                                                          *
************************************************************


Node Point Information:

Fixity condition definitions:
    s=spring and value
    r=complete release
    f=complete fixity with imposed displacement

node    name    coordinates    -----------fixity --------
  #              X       Y     X-dir.     Y-dir.   Rotation
    1 S01.00     0.00     0.00   r          r          r
    2 S01.01     2.00     0.00   r          r          r
    3 C01.01     2.00    -1.00   r          r          r
    4 P01.01     2.00    -2.00   f 0.0000   f 0.0000   r
    5 S02.01    12.57     0.00   r          r          r
    6 S02.02    23.14     0.00   r          r          r
    7 S02.03    33.71     0.00   r          r          r
    8 S02.04    44.28     0.00   r          r          r
    9 S02.05    54.85     0.00   r          r          r
   10 S02.06    65.42     0.00   r          r          r
   11 S02.07    75.99     0.00   r          r          r
   12 S02.08    86.56     0.00   r          r          r
   13 S02.09    97.13     0.00   r          r          r
   14 S02.10   107.70     0.00   r          r          r
   15 S02.11   115.70     0.00   r          r          r
   16 S02.12   123.70     0.00   r          r          r
   17 S02.13   127.96     0.00   r          r          r
   18 C02.01   127.96    -3.38   r          r          r
   19 C02.02   127.96   -15.31   r          r          r
   20 C02.03   127.96   -27.24   r          r          r
   21 C02.04   127.96   -39.17   r          r          r
   22 P02.01   127.96   -41.22   s 2.7e+002  r          r
   23 P02.02   127.96   -43.27   s 8.3e+002  r          r
   24 P02.03   127.96   -45.32   s 1.3e+003  r          r
   25 P02.04   127.96   -47.37   f 0.0000   f 0.0000   r
   26 S03.01   132.22     0.00   r          r          r
   27 S03.02   140.22     0.00   r          r          r
   28 S03.03   148.22     0.00   r          r          r
   29 S03.04   160.97     0.00   r          r          r
   30 S03.05   173.72     0.00   r          r          r
   31 S03.06   186.47     0.00   r          r          r
   32 S03.07   199.22     0.00   r          r          r
   33 S03.08   211.97     0.00   r          r          r
```

```
   34 S03.09   224.72     0.00   r           r           r
   35 S03.10   237.47     0.00   r           r           r
   36 S03.11   250.22     0.00   r           r           r
   37 S03.12   262.97     0.00   r           r           r
   38 S03.13   275.72     0.00   r           r           r
   39 S03.14   283.72     0.00   r           r           r
   40 S03.15   291.72     0.00   r           r           r
   41 S03.16   295.98     0.00   r           r           r
   42 C03.01   295.98    -3.38   r           r           r
   43 C03.02   295.98   -15.33   r           r           r
   44 C03.03   295.98   -27.28   r           r           r
   45 C03.04   295.98   -39.23   r           r           r
   46 P03.01   295.98   -41.46   s 3.2e+002  r           r
   47 P03.02   295.98   -43.69   s 9.2e+002  r           r
   48 P03.03   295.98   -45.92   s 1.5e+003  r           r
   49 P03.04   295.98   -48.15   s 2e+003    r           r
   50 P03.05   295.98   -50.38   f 0.0000    f 0.0000    r
   51 S04.01   300.24     0.00   r           r           r
   52 S04.02   308.24     0.00   r           r           r
   53 S04.03   316.24     0.00   r           r           r
   54 S04.04   326.01     0.00   r           r           r
   55 S04.05   335.78     0.00   r           r           r
   56 S04.06   345.55     0.00   r           r           r
   57 S04.07   355.32     0.00   r           r           r
   58 S04.08   365.09     0.00   r           r           r
   59 S04.09   374.86     0.00   r           r           r
   60 S04.10   384.63     0.00   r           r           r
   61 S04.11   394.40     0.00   r           r           r
   62 S04.12   404.17     0.00   r           r           r
   63 S04.13   413.94     0.00   r           r           r
   64 C04.01   413.94    -1.00   r           r           r
   65 P04.01   413.94    -2.00   f 0.0000    f 0.0000    r
   66 S05.01   415.94     0.00   s 7.7e+003  r           r


Spring Information at node points:

k's = k/ft or ft-k/rad.;  d's = ft or rad.
node   spring      k1      d1      k2      d2
  #    name
   22  P02X01       272.74  0.149         0.00  1.000         0.00 1000.000
   23  P02X02       828.36  0.105         0.00  1.000         0.00 1000.000
   24  P02X03      1326.91  0.106         0.00  1.000         0.00 1000.000
   46  P03X01       317.46  0.149         0.00  1.000         0.00 1000.000
   47  P03X02       919.77  0.110         0.00  1.000         0.00 1000.000
   48  P03X03      1476.21  0.109         0.00  1.000         0.00 1000.000
   49  P03X04      2038.47  0.109         0.00  1.000         0.00 1000.000
   66  S05X01      7723.00  0.249         0.00  1.000         0.00 1000.000


Structural Setup:
Spans= 5, Columns= 4, Piles= 4, Link Beams= 0


Element Information:
   element     nodes      depth
 # name fix    i  j      L   d   area    Ei      Ef      Icr      q      Mpp    Mpn  tol
status
  1 S01-01 rn   1   2   2.00 6.8 103.5 629528  60480 826.75  -0.01  99999  99999 0.02 e
  2 C01-01 rs   2   3   1.00 6.0 56.5 629528  62107  94.88   0.00  99999  99999 0.02 e
  3 P01-01 rn   3   4   1.00 6.0 56.5 629528  62107  47.44   0.00  99999  99999 0.02 e
  4 S02-01 rn   2   5  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
  5 S02-02 rn   5   6  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
  6 S02-03 rn   6   7  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
  7 S02-04 rn   7   8  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
  8 S02-05 rn   8   9  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
  9 S02-06 rn   9  10  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 10 S02-07 rn  10  11  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
```

**APPENDIX – S**

(*wFRAME* Output File – To Determine Superstructure Forces due to Column Hinging Continues, Case 1)

```
 11 S02-08 rn  11  12  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 12 S02-09 rn  12  13  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 13 S02-10 rn  13  14  10.57 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 14 S02-11 rn  14  15   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 15 S02-12 rn  15  16   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 16 S02-13 rn  16  17   4.26 6.8 115.6 629528  60480 826.75  -0.01  99999  99999 0.02 e
 17 C02-01 rn  17  18   3.38 6.0 56.5 629528  62107  94.88   0.00  99999  99999 0.02 e
 18 C02-02 rn  18  19  11.93 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 19 C02-03 rn  19  20  11.93 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 20 C02-04 rn  20  21  11.93 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 21 P02-01 rn  21  22   2.05 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 22 P02-02 rn  22  23   2.05 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 23 P02-03 rn  23  24   2.05 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 24 P02-04 re  24  25   2.05 6.0 56.5 629528  62107  47.44   0.00  32060  34566 0.02 e
 25 S03-01 rn  17  26   4.26 6.8 115.6 629528  60480 826.75  -0.01  99999  99999 0.02 e
 26 S03-02 rn  26  27   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 27 S03-03 rn  27  28   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 28 S03-04 rn  28  29  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 29 S03-05 rn  29  30  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 30 S03-06 rn  30  31  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 31 S03-07 rn  31  32  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 32 S03-08 rn  32  33  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 33 S03-09 rn  33  34  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 34 S03-10 rn  34  35  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 35 S03-11 rn  35  36  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 36 S03-12 rn  36  37  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 37 S03-13 rn  37  38  12.75 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 38 S03-14 rn  38  39   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 39 S03-15 rn  39  40   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 40 S03-16 rn  40  41   4.26 6.8 115.6 629528  60480 826.75  -0.01  99999  99999 0.02 e
 41 C03-01 rn  41  42   3.38 6.0 56.5 629528  62107  94.44   0.00  99999  99999 0.02 e
 42 C03-02 rn  42  43  11.95 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 43 C03-03 rn  43  44  11.95 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 44 C03-04 rn  44  45  11.95 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 45 P03-01 rn  45  46   2.23 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 46 P03-02 rn  46  47   2.23 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 47 P03-03 rn  47  48   2.23 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 48 P03-04 rn  48  49   2.23 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 49 P03-05 re  49  50   2.23 6.0 56.5 629528  62107  47.22   0.00  34512  31835 0.02 e
 50 S04-01 rn  41  51   4.26 6.8 115.6 629528  60480 826.75  -0.01  99999  99999 0.02 e
 51 S04-02 rn  51  52   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 52 S04-03 rn  52  53   8.00 6.8 109.6 629528  60480 778.93  -0.01  99999  99999 0.02 e
 53 S04-04 rn  53  54   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 54 S04-05 rn  54  55   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 55 S04-06 rn  55  56   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 56 S04-07 rn  56  57   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 57 S04-08 rn  57  58   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 58 S04-09 rn  58  59   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 59 S04-10 rn  59  60   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 60 S04-11 rn  60  61   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 61 S04-12 rn  61  62   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 62 S04-13 rn  62  63   9.77 6.8 103.5 629528  60480 731.10  -0.01  99999  99999 0.02 e
 63 C04-01 rs  63  64   1.00 6.0 56.5 629528  62107  94.44   0.00  99999  99999 0.02 e
 64 P04-01 rn  64  65   1.00 6.0 56.5 629528  62107  47.22   0.00  99999  99999 0.02 e
 65 S05-01 rn  63  66   2.00 6.8 103.5 629528  60480 826.75  -0.01  99999  99999 0.02 e
bandwidth of the problem = 11
Number of rows and columns in strage = 198 x 33
---------------------------------------------------------
---------------------------------------------------------
---------------------------------------------------------

Cumulative Results of analysis at end of stage   8

Plastic Action at:
                      Lat. Force        / Deflection
Element/ Stage/ Code/  *g (DL=    4.2)  /    (in)
S05X01     1      2      565.5476          3.0605
P03X02     2      2      693.9159          6.8393
```

| | | | | |
|---|---|---|---|---|
| P03X01 | 3 | 2 | 698.0762 | 6.9630 |
| P02X01 | 4 | 2 | 774.1634 | 9.2504 |
| P02X02 | 5 | 2 | 790.7322 | 9.7510 |
| P03X03 | 6 | 2 | 801.2447 | 10.0718 |
| C02-02 | 7 | rs | 823.5609 | 10.7641 |
| C03-02 | 8 | rs | 826.7094 | 10.9793 |

| node# | name | ---------- GLOBAL --------- Displ.x | Displ.y | Rotation |
|---|---|---|---|---|
| 1 | S01.00 | 0.91494 | -0.00139 | 0.00070 |
| 2 | S01.01 | 0.91494 | 0.00001 | 0.00070 |
| 3 | C01.01 | 0.45747 | 0.00000 | -0.45747 |
| 4 | P01.01 | 0.00000 | 0.00000 | -0.45747 |
| 5 | S02.01 | 0.91493 | 0.00733 | 0.00068 |
| 6 | S02.02 | 0.91491 | 0.01435 | 0.00064 |
| 7 | S02.03 | 0.91487 | 0.02074 | 0.00057 |
| 8 | S02.04 | 0.91482 | 0.02619 | 0.00046 |
| 9 | S02.05 | 0.91475 | 0.03040 | 0.00033 |
| 10 | S02.06 | 0.91467 | 0.03304 | 0.00017 |
| 11 | S02.07 | 0.91457 | 0.03381 | -0.00003 |
| 12 | S02.08 | 0.91446 | 0.03238 | -0.00025 |
| 13 | S02.09 | 0.91434 | 0.02846 | -0.00050 |
| 14 | S02.10 | 0.91420 | 0.02172 | -0.00078 |
| 15 | S02.11 | 0.91409 | 0.01461 | -0.00100 |
| 16 | S02.12 | 0.91397 | 0.00569 | -0.00123 |
| 17 | S02.13 | 0.91391 | 0.00017 | -0.00136 |
| 18 | C02.01 | 0.90585 | 0.00016 | -0.00339 |
| 19 | C02.02 | 0.78568 | 0.00012 | -0.01570 |
| 20 | C02.03 | 0.54645 | 0.00007 | -0.02377 |
| 21 | C02.04 | 0.23382 | 0.00003 | -0.02801 |
| 22 | P02.01 | 0.17604 | 0.00002 | -0.02835 |
| 23 | P02.02 | 0.11766 | 0.00001 | -0.02858 |
| 24 | P02.03 | 0.05892 | 0.00001 | -0.02871 |
| 25 | P02.04 | 0.00000 | 0.00000 | 0.00000 |
| 26 | S03.01 | 0.91390 | -0.00523 | -0.00118 |
| 27 | S03.02 | 0.91386 | -0.01338 | -0.00086 |
| 28 | S03.03 | 0.91381 | -0.01907 | -0.00057 |
| 29 | S03.04 | 0.91372 | -0.02355 | -0.00015 |
| 30 | S03.05 | 0.91361 | -0.02325 | 0.00018 |
| 31 | S03.06 | 0.91347 | -0.01929 | 0.00042 |
| 32 | S03.07 | 0.91332 | -0.01282 | 0.00058 |
| 33 | S03.08 | 0.91314 | -0.00498 | 0.00064 |
| 34 | S03.09 | 0.91295 | 0.00309 | 0.00061 |
| 35 | S03.10 | 0.91273 | 0.01025 | 0.00050 |
| 36 | S03.11 | 0.91249 | 0.01537 | 0.00029 |
| 37 | S03.12 | 0.91223 | 0.01729 | 0.00000 |
| 38 | S03.13 | 0.91195 | 0.01487 | -0.00039 |
| 39 | S03.14 | 0.91178 | 0.01070 | -0.00066 |
| 40 | S03.15 | 0.91160 | 0.00425 | -0.00096 |
| 41 | S03.16 | 0.91150 | -0.00020 | -0.00113 |
| 42 | C03.01 | 0.90448 | -0.00018 | -0.00301 |
| 43 | C03.02 | 0.79901 | -0.00014 | -0.01407 |
| 44 | C03.03 | 0.58202 | -0.00009 | -0.02167 |
| 45 | C03.04 | 0.29496 | -0.00004 | -0.02580 |
| 46 | P03.01 | 0.23698 | -0.00003 | -0.02619 |
| 47 | P03.02 | 0.17826 | -0.00003 | -0.02646 |
| 48 | P03.03 | 0.11906 | -0.00002 | -0.02662 |
| 49 | P03.04 | 0.05959 | -0.00001 | -0.02671 |
| 50 | P03.05 | 0.00000 | 0.00000 | 0.00000 |
| 51 | S04.01 | 0.91145 | -0.00476 | -0.00102 |
| 52 | S04.02 | 0.91133 | -0.01206 | -0.00081 |
| 53 | S04.03 | 0.91121 | -0.01776 | -0.00062 |
| 54 | S04.04 | 0.91104 | -0.02267 | -0.00039 |
| 55 | S04.05 | 0.91086 | -0.02546 | -0.00019 |
| 56 | S04.06 | 0.91067 | -0.02639 | -0.00001 |
| 57 | S04.07 | 0.91046 | -0.02567 | 0.00015 |
| 58 | S04.08 | 0.91025 | -0.02355 | 0.00028 |
| 59 | S04.09 | 0.91002 | -0.02025 | 0.00039 |

```
   60 S04.10  0.90978 -0.01601  0.00047
   61 S04.11  0.90952 -0.01107  0.00053
   62 S04.12  0.90926 -0.00565  0.00057
   63 S04.13  0.90898 -0.00001  0.00058
   64 C04.01  0.45449  0.00000 -0.45449
   65 P04.01  0.00000  0.00000 -0.45449
   66 S05.01  0.90892  0.00116  0.00058

element   node  -------- local -----------  ------ element ----------
#    name  fix    displ.x  displ.y  rotation  axial    shear     moment
  1 S01-01 rn   1  0.91494 -0.00139  0.00070     7.96     -0.05     -0.05
                2  0.91494  0.00001  0.00070    -7.96      0.07     -0.15
  2 C01-01 rs   2 -0.00001  0.91494 -0.45747  -121.46     -1.16      2.83
                3  0.00000  0.45747 -0.45747   121.46      1.16     -1.88
  3 P01-01 rn   3  0.00000  0.45747 -0.45747  -121.45      2.84      3.23
                4  0.00000  0.00000 -0.45747   121.45     -2.84      0.54
  4 S02-01 rn   2  0.91494  0.00001  0.00070    66.88   -121.49      0.11
                5  0.91493  0.00733  0.00068   -66.88    121.59  -1284.78
  5 S02-02 rn   5  0.91493  0.00733  0.00068   154.33   -121.59   1284.77
                6  0.91491  0.01435  0.00064  -154.33    121.70  -2570.57
  6 S02-03 rn   6  0.91491  0.01435  0.00064   241.78   -121.69   2570.60
                7  0.91487  0.02074  0.00057  -241.78    121.80  -3857.45
  7 S02-04 rn   7  0.91487  0.02074  0.00057   328.97   -121.79   3857.49
                8  0.91482  0.02619  0.00046  -328.97    121.90  -5145.39
  8 S02-05 rn   8  0.91482  0.02619  0.00046   416.46   -121.91   5145.35
                9  0.91475  0.03040  0.00033  -416.46    122.01  -6434.50
  9 S02-06 rn   9  0.91475  0.03040  0.00033   503.92   -122.01   6434.45
               10  0.91467  0.03304  0.00017  -503.92    122.12  -7724.72
 10 S02-07 rn  10  0.91467  0.03304  0.00017   591.24   -122.12   7724.77
               11  0.91457  0.03381 -0.00003  -591.24    122.23  -9016.14
 11 S02-08 rn  11  0.91457  0.03381 -0.00003   678.73   -122.23   9016.08
               12  0.91446  0.03238 -0.00025  -678.73    122.33 -10308.60
 12 S02-09 rn  12  0.91446  0.03238 -0.00025   765.98   -122.32  10308.54
               13  0.91434  0.02846 -0.00050  -765.98    122.43 -11602.01
 13 S02-10 rn  13  0.91434  0.02846 -0.00050   853.26   -122.42  11602.04
               14  0.91420  0.02172 -0.00078  -853.26    122.53 -12896.63
 14 S02-11 rn  14  0.91420  0.02172 -0.00078   929.86   -122.53  12896.71
               15  0.91409  0.01461 -0.00100  -929.86    122.61 -13877.31
 15 S02-12 rn  15  0.91409  0.01461 -0.00100   996.09   -122.62  13877.32
               16  0.91397  0.00569 -0.00123  -996.09    122.70 -14858.59
 16 S02-13 rn  16  0.91397  0.00569 -0.00123  1045.60   -122.67  14858.54
               17  0.91391  0.00017 -0.00136 -1045.60    122.72 -15381.23
 17 C02-01 rn  17 -0.00017  0.91391 -0.00136  -129.63    802.31  37277.61
               18 -0.00016  0.90585 -0.00339   129.63   -802.31 -34565.06
 18 C02-02 rs  18 -0.00016  0.90585 -0.00381  -129.70    803.16  34566.00
               19 -0.00012  0.78568 -0.01570   129.70   -803.16 -24984.38
 19 C02-03 rn  19 -0.00012  0.78568 -0.01570  -129.70    803.20  24984.45
               20 -0.00007  0.54645 -0.02377   129.70   -803.20 -15402.32
 20 C02-04 rn  20 -0.00007  0.54645 -0.02377  -129.70    803.19  15402.39
               21 -0.00003  0.23382 -0.02801   129.70   -803.19  -5820.25
 21 P02-01 rn  21 -0.00003  0.23382 -0.02801  -129.70    803.01   5820.04
               22 -0.00002  0.17604 -0.02835   129.70   -803.01  -4173.57
 22 P02-02 rn  22 -0.00002  0.17604 -0.02835  -129.70    762.93   4173.57
               23 -0.00001  0.11766 -0.02858   129.70   -762.93  -2608.72
 23 P02-03 rn  23 -0.00001  0.11766 -0.02858  -129.70    675.28   2608.72
               24 -0.00001  0.05892 -0.02871   129.70   -675.28  -1224.19
 24 P02-04 re  24 -0.00001  0.05892 -0.02871  -129.70    596.97   1223.95
               25  0.00000  0.00000 -0.02876   129.70   -596.97      0.19
 25 S03-01 rn  17  0.91391  0.00017 -0.00136   275.24   -252.34 -21895.10
               26  0.91390 -0.00523 -0.00118  -275.24    252.39  20819.98
 26 S03-02 rn  26  0.91390 -0.00523 -0.00118   323.91   -252.44 -20820.30
               27  0.91386 -0.01338 -0.00086  -323.91    252.52  18800.48
 27 S03-03 rn  27  0.91386 -0.01338 -0.00086   390.05   -252.52 -18800.49
               28  0.91381 -0.01907 -0.00057  -390.05    252.60  16780.03
 28 S03-04 rn  28  0.91381 -0.01907 -0.00057   476.18   -252.60 -16780.05
               29  0.91372 -0.02355 -0.00015  -476.18    252.73  13558.59
 29 S03-05 rn  29  0.91372 -0.02355 -0.00015   581.21   -252.73 -13558.59
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 30 | 0.91361 | -0.02325 | 0.00018 | -581.21 | 252.86 | 10335.46 |
| 30 | S03-06 rn | 30 | 0.91361 | -0.02325 | 0.00018 | 686.60 | -252.86 | -10335.48 |
| | | 31 | 0.91347 | -0.01929 | 0.00042 | -686.60 | 252.99 | 7110.70 |
| 31 | S03-07 rn | 31 | 0.91347 | -0.01929 | 0.00042 | 792.32 | -252.99 | -7110.76 |
| | | 32 | 0.91332 | -0.01282 | 0.00058 | -792.32 | 253.11 | 3884.32 |
| 32 | S03-08 rn | 32 | 0.91332 | -0.01282 | 0.00058 | 897.62 | -253.11 | -3884.32 |
| | | 33 | 0.91314 | -0.00498 | 0.00064 | -897.62 | 253.24 | 656.29 |
| 33 | S03-09 rn | 33 | 0.91314 | -0.00498 | 0.00064 | 1002.73 | -253.24 | -656.31 |
| | | 34 | 0.91295 | 0.00309 | 0.00061 | -1002.73 | 253.37 | -2573.30 |
| 34 | S03-10 rn | 34 | 0.91295 | 0.00309 | 0.00061 | 1107.96 | -253.37 | 2573.31 |
| | | 35 | 0.91273 | 0.01025 | 0.00050 | -1107.96 | 253.49 | -5804.55 |
| 35 | S03-11 rn | 35 | 0.91273 | 0.01025 | 0.00050 | 1213.10 | -253.49 | 5804.57 |
| | | 36 | 0.91249 | 0.01537 | 0.00029 | -1213.10 | 253.62 | -9037.41 |
| 36 | S03-12 rn | 36 | 0.91249 | 0.01537 | 0.00029 | 1318.15 | -253.62 | 9037.43 |
| | | 37 | 0.91223 | 0.01729 | 0.00000 | -1318.15 | 253.75 | -12271.86 |
| 37 | S03-13 rn | 37 | 0.91223 | 0.01729 | 0.00000 | 1423.72 | -253.75 | 12271.88 |
| | | 38 | 0.91195 | 0.01487 | -0.00039 | -1423.72 | 253.87 | -15507.93 |
| 38 | S03-14 rn | 38 | 0.91195 | 0.01487 | -0.00039 | 1509.61 | -253.87 | 15507.97 |
| | | 39 | 0.91178 | 0.01070 | -0.00066 | -1509.61 | 253.95 | -17539.28 |
| 39 | S03-15 rn | 39 | 0.91178 | 0.01070 | -0.00066 | 1575.32 | -253.95 | 17539.30 |
| | | 40 | 0.91160 | 0.00425 | -0.00096 | -1575.32 | 254.03 | -19571.26 |
| 40 | S03-16 rn | 40 | 0.91160 | 0.00425 | -0.00096 | 1625.24 | -254.03 | 19571.27 |
| | | 41 | 0.91150 | -0.00020 | -0.00113 | -1625.24 | 254.07 | $\boxed{\mathbf{-20653.44}}$ |
| 41 | C03-01 rn | 41 | 0.00020 | 0.91150 | -0.00113 | 139.19 | 720.73 | 34272.61 |
| | | 42 | 0.00018 | 0.90448 | -0.00301 | -139.19 | -720.73 | -31834.53 |
| 42 | C03-02 rs | 42 | 0.00018 | 0.90448 | -0.00301 | 139.37 | 721.63 | 31835.00 |
| | | 43 | 0.00014 | 0.79901 | -0.01407 | -139.37 | -721.63 | -23211.58 |
| 43 | C03-03 rn | 43 | 0.00014 | 0.79901 | -0.01407 | 139.37 | 721.60 | 23211.54 |
| | | 44 | 0.00009 | 0.58202 | -0.02167 | -139.37 | -721.60 | -14588.37 |
| 44 | C03-04 rn | 44 | 0.00009 | 0.58202 | -0.02167 | 139.37 | 721.60 | 14588.39 |
| | | 45 | 0.00004 | 0.29496 | -0.02580 | -139.37 | -721.60 | -5965.15 |
| 45 | P03-01 rn | 45 | 0.00004 | 0.29496 | -0.02580 | 139.37 | 722.14 | 5965.03 |
| | | 46 | 0.00003 | 0.23698 | -0.02619 | -139.37 | -722.14 | -4354.41 |
| 46 | P03-02 rn | 46 | 0.00003 | 0.23698 | -0.02619 | 139.37 | 675.42 | 4356.10 |
| | | 47 | 0.00003 | 0.17826 | -0.02646 | -139.37 | -675.42 | -2849.67 |
| 47 | P03-03 rn | 47 | 0.00003 | 0.17826 | -0.02646 | 139.37 | 573.73 | 2849.93 |
| | | 48 | 0.00002 | 0.11906 | -0.02662 | -139.37 | -573.73 | -1570.17 |
| 48 | P03-04 rn | 48 | 0.00002 | 0.11906 | -0.02662 | 139.37 | 413.04 | 1570.32 |
| | | 49 | 0.00001 | 0.05959 | -0.02671 | -139.37 | -413.04 | -649.73 |
| 49 | P03-05 re | 49 | 0.00001 | 0.05959 | -0.02671 | 139.37 | 291.41 | 649.92 |
| | | 50 | 0.00000 | 0.00000 | -0.02673 | -139.37 | -291.41 | 0.02 |
| 50 | S04-01 rn | 41 | 0.91150 | -0.00020 | -0.00113 | 937.33 | -114.89 | $\boxed{\mathbf{-13620.04}}$ |
| | | 51 | 0.91145 | -0.00476 | -0.00102 | -937.33 | 114.93 | 13130.54 |
| 51 | S04-02 rn | 51 | 0.91145 | -0.00476 | -0.00102 | 985.41 | -114.90 | -13130.79 |
| | | 52 | 0.91133 | -0.01206 | -0.00081 | -985.41 | 114.98 | 12211.28 |
| 52 | S04-03 rn | 52 | 0.91133 | -0.01206 | -0.00081 | 1051.28 | -114.98 | -12211.29 |
| | | 53 | 0.91121 | -0.01776 | -0.00062 | -1051.28 | 115.06 | 11291.11 |
| 53 | S04-04 rn | 53 | 0.91121 | -0.01776 | -0.00062 | 1124.34 | -115.05 | -11291.12 |
| | | 54 | 0.91104 | -0.02267 | -0.00039 | -1124.34 | 115.14 | 10166.64 |
| 54 | S04-05 rn | 54 | 0.91104 | -0.02267 | -0.00039 | 1205.35 | -115.16 | -10166.66 |
| | | 55 | 0.91086 | -0.02546 | -0.00019 | -1205.35 | 115.26 | 9041.13 |
| 55 | S04-06 rn | 55 | 0.91086 | -0.02546 | -0.00019 | 1285.70 | -115.24 | -9041.08 |
| | | 56 | 0.91067 | -0.02639 | -0.00001 | -1285.70 | 115.34 | 7914.69 |
| 56 | S04-07 rn | 56 | 0.91067 | -0.02639 | -0.00001 | 1366.44 | -115.36 | -7914.63 |
| | | 57 | 0.91046 | -0.02567 | 0.00015 | -1366.44 | 115.46 | 6787.08 |
| 57 | S04-08 rn | 57 | 0.91046 | -0.02567 | 0.00015 | 1447.19 | -115.47 | -6787.06 |
| | | 58 | 0.91025 | -0.02355 | 0.00028 | -1447.19 | 115.56 | 5658.44 |
| 58 | S04-09 rn | 58 | 0.91025 | -0.02355 | 0.00028 | 1528.20 | -115.57 | -5658.47 |
| | | 59 | 0.91002 | -0.02025 | 0.00039 | -1528.20 | 115.67 | 4528.84 |
| 59 | S04-10 rn | 59 | 0.91002 | -0.02025 | 0.00039 | 1608.68 | -115.68 | -4528.86 |
| | | 60 | 0.90978 | -0.01601 | 0.00047 | -1608.68 | 115.78 | 3398.19 |
| 60 | S04-11 rn | 60 | 0.90978 | -0.01601 | 0.00047 | 1689.91 | -115.79 | -3398.23 |
| | | 61 | 0.90952 | -0.01107 | 0.00053 | -1689.91 | 115.88 | 2266.52 |
| 61 | S04-12 rn | 61 | 0.90952 | -0.01107 | 0.00053 | 1770.60 | -115.89 | -2266.52 |
| | | 62 | 0.90926 | -0.00565 | 0.00057 | -1770.60 | 115.99 | 1133.80 |
| 62 | S04-13 rn | 62 | 0.90926 | -0.00565 | 0.00057 | 1851.17 | -115.99 | -1133.79 |
| | | 63 | 0.90898 | -0.00001 | 0.00058 | -1851.17 | 116.09 | 0.10 |
| 63 | C04-01 rs | 63 | 0.00001 | 0.90898 | -0.45449 | 116.10 | -0.48 | -4.62 |

```
              64  0.00000  0.45449 -0.45449   -116.10      0.48     -6.54
 64 P04-01 rn  64  0.00000  0.45449 -0.45449    116.10     -8.97     -4.32
              65  0.00000  0.00000 -0.45449   -116.10      8.97     -4.18
 65 S05-01 rn  63  0.90898 -0.00001  0.00058   1915.77      0.03     -0.06
              66  0.90892  0.00116  0.00058  -1915.77     -0.01      0.02
```

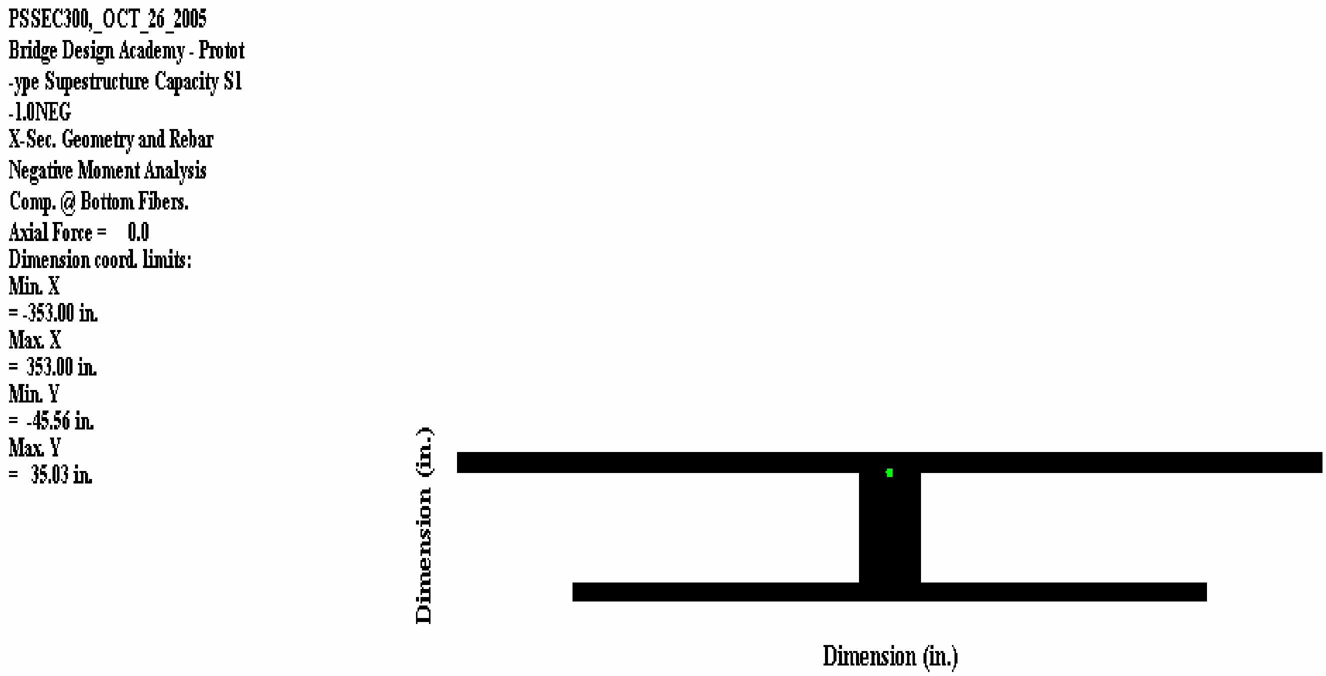
# APPENDIX - T

(*PSSECx* Input File)

```
PSSEC300,_OCT_26_2005
Bridge Design Academy - Prototype Supestructure Capacity S1 1.0NEG
Number of different types of concrete
1
For each concrete type input:
Type number; Model code= 0 simple(unconfined/confined), 1 Mander's (unconfined)
strength f'c0 (ksi), strain ec0, strength fcu (ksi), ult. strain ecu, conc. density
1    1
5.200   .002       0.5    0.0025      150
Number of different types of P/S steel
1
For each type, 1st line for tensile parameters,2nd line for cmpressive parameters
type#;E;fy;strain hard. factor;fu;ult. strain;PS-code: 0 tendons, 1 otherwise
      E;fy;strain hard. factor;fu;ult. strain
1   28500    245    2    270   0.030   0
     0        0     0     0      0
Number of different types of mild steel
1
For each steel type input:
Type number;Model code= 0 simple, 1 complex
E(ksi);fy(ksi);strain hard. factor;fu(ksi);ultimate strain
1    1
29000    68   6.41   95   0.09
Number of Conc. Subsections
1
For each Subsec.:Subsection #,Section shape type, Concrete type, No. of fibers
Subsec. Dim.(in):(See Manual for input parameters.)
Subsec. Dim.(in):(See Manual for input parameters.)
Global coord. of the center of Subsec.: Xg, Yg
1  I-shaped,    1   200
706.0  48.0  517.0
81.0  9.125  8.25
0   -5.26
Number of P/S steel groups
1
For each group:group#;P/S type;x-coord.(in);y-coord.(in);area(in^2);P/S force
1    1     0    25.4412     38.28   6157
Number of mild steel rebar cages (rebar distributed around the perimeter)
0
cage#;steel type;cage shape;#of bars;x(in) of 1st bar(y=0);area(in^2)of bar
Number of mild steel groups (no logical pattern for distribution)
2   n
group#;steel type;x-coord.(in); y-coord.(in); area(in^2)
1   1    0   31.80  47.40
2   1    0  -42.13  34.76
Non P/S Axial load on mid-depth of section (Kips)(+ sign=compression)
0
Numerical Computation Factor (1 to 10)
5
Computer Graphics Card identifier: 0 none; 2 CGA; 3 Hercules; 9 EGA; 12 VGA
12
Output control: 0 short; 1 long output
1
X-Sec. plot control (0=no plot, 1=each stage, 2=every iteration of each step)
0
Analysis Control:  p - Positive moment, n - Negative moment
n
```

# APPENDIX – U

(*PSSECx* Model for Superstructure)



# APPENDIX – V

(Partial Output from PSSECx Run)

```
                                   05-15-2006
********   SECx   ********

        DUCTILITY and STRENGTH of
Rectangular, T-, I-, Hammer, Octagonal, Circular, Ring,
     and Hollowed shaped Prestressed and Reinforced
      Concrete Sections using fiber models
            Ver. 3.00, OCT-26-2005

Copyright (C) 2005 By Mark Seyed and Don Lee.
This program should not be distributed under any condition.
This release is for demo ONLY (beta testing is not complete).

Caltrans or the author make no expressed or implied warranty of any
kind with regard to this program. In no event shall the author or
Caltrans be held liable for incidental or consequential damages
arising out of the use of this program.

JOB TITLE:    Bridge Design Academy - Prototype Supestructure Capacity S1 1.0NEG


       Concrete Data, Complex Model, Mander's unconfined

Concrete Type                          =      1
Compressive Strength (max.)    (ksi)  =  5.200
Strain at max. Strength                = .00200
Strength at Ultimate Strain    (ksi)  =  0.000
Ultimate strain                        = .00500
Unit Weight (pcf)                      = 150.00

       Prestressing Steel Data

 Material  Yield    Hardening  Ultimate  Yield   Ultimate  Modulus
   No.     Strain    Strain     Strain   Stress   Stress   of Elasticity
                                          ksi      ksi      ksi
    1   0.00860  0.00860  0.03000    245.10    270.00  28500.00 Tensile prop.
        0.00000  0.00000  0.00000      0.00      0.00      0.00 Compressive prop.
Prestress element type #      1 is 7-wire and Low-Relaxation Tendon
 with 270 ksi strands.
 ( Refer to PCI Design Handbook 4th Edition.)

       Mild Steel Reinforcing Data

 Material   Yield    Hardening   Ultimate   Yield   Ultimate
   No.      Strain    Strain      Strain    Stress   Stress
                                             ksi      ksi
    1    0.00234    0.01503    0.09000     68.00     95.00

     Rectangular, T-, or I-shaped section information

Depth of Section            (in.)    =   81.00
Top Flange width            (in.)    =  706.00
Top Flange thickness        (in.)    =    9.13
Bot Flange width            (in.)    =  517.00
Bot Flange thickness        (in.)    =    8.25
Web thickness               (in.)    =   48.00

        Concrete fiber information

  Fiber   Material     x       y     area
    #        #        (in)    (in)  (in^2)
    1    1.0      0.00    -45.56    203.11
    2    1.0      0.00    -45.17    203.11
    3    1.0      0.00    -44.78    203.11
    4    1.0      0.00    -44.38    203.11
    5    1.0      0.00    -43.99    203.11
    6    1.0      0.00    -43.60    203.11
    7    1.0      0.00    -43.21    203.11
```

```
   8    1.0      0.00    -42.81    203.11
   9    1.0      0.00    -42.42    203.11
  10    1.0      0.00    -42.03    203.11
  11    1.0      0.00    -41.63    203.11
  12    1.0      0.00    -41.24    203.11
  13    1.0      0.00    -40.85    203.11
  14    1.0      0.00    -40.46    203.11
  15    1.0      0.00    -40.06    203.11
  ..........................................
  ..........................................
  ..........................................

 188    1.0      0.00     30.06    292.83
 189    1.0      0.00     30.47    292.83
 190    1.0      0.00     30.88    292.83
 191    1.0      0.00     31.30    292.83
 192    1.0      0.00     31.71    292.83
 193    1.0      0.00     32.13    292.83
 194    1.0      0.00     32.54    292.83
 195    1.0      0.00     32.96    292.83
 196    1.0      0.00     33.37    292.83
 197    1.0      0.00     33.79    292.83
 198    1.0      0.00     34.20    292.83
 199    1.0      0.00     34.62    292.83
 200    1.0      0.00     35.03    292.83


      Prestressing Steel Fiber Data

 Fiber  Material      x          y         area    P/S force
   No.    No.        (in)       (in)       (in^2)    Kips

     1     1       0.00      25.44      38.28    6157.00

    Total P/S force on the section =    6157.0 kips
    Total moment due to P/S about point (0, 0)  =   13053.5 ft-kip

      Mild Steel Fiber Data

 Fiber  Material      x          y         area
   No.    No.        (in)       (in)       (in^2)

     1     1       0.00      31.80      47.40
     2     1       0.00     -42.13      34.76

Axial load at mid-depth of section (kip)(positive means compression) =     0.0

***************************************************
* Analysis Results ---   Negative Moment Capacity *
***************************************************

 Initial state due to P/S without non-P/S axial force:
 N.A. Loc.     Curvature     Conc. Strain @ max. compressed fiber
    -41.50    0.0000023         0.00017950

 Undeformed P/S element position w.r.t. reference plane
 P/S Fiber    Loc.(y)      Undef. pos.      Conc. Strain @ same loc.
      1      25.44     -0.0058006         -0.0001570


Force Equilibrium Condition of the x-section:

     Max.             Max.
     Conc.    Neutral Steel           Steel
     Strain    Axis   Strain Conc.    force       P/S     Net  Curvature Moment
step epscmax   in.    Tens.  Comp.  Comp. Tens.   force   force  in/in   (K-ft)
 0 -.00001  -41.50 -.00000   5923.   236.    -1. -6157.  -0.8 0.000002      -4.
 1 -.00001  -42.26 0.00000   5923.   235.     0. -6158.  -0.4 0.000002    -147.
```

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | -.00001 | -43.05 | 0.00000 | 5923. | 236. | 0. | -6158. | -0.5 | 0.000002 | -307. |
| 3 | -.00000 | -43.86 | 0.00000 | 5923. | 236. | 0. | -6159. | 0.3 | 0.000002 | -486. |
| 4 | -.00000 | -44.70 | 0.00000 | 5924. | 237. | 0. | -6160. | 0.2 | 0.000002 | -683. |
| 5 | 0.00000 | -45.56 | 0.00000 | 5925. | 237. | 0. | -6161. | -0.7 | 0.000002 | -899. |
| 6 | 0.00010 | 9055.25 | 0.00000 | 5983. | 237. | 0. | -6220. | -0.4 | -.000000 | -13142. |
| 7 | 0.00011 | 362.50 | 0.00000 | 5990. | 237. | 0. | -6227. | -0.3 | -.000000 | -14634. |
| 8 | 0.00013 | 174.76 | 0.00000 | 5997. | 237. | 0. | -6235. | 0.8 | -.000001 | -16309. |
| 9 | 0.00014 | 110.77 | 0.00000 | 6006. | 237. | 0. | -6244. | 0.9 | -.000001 | -18186. |
| 10 | 0.00016 | 78.67 | 0.00000 | 6017. | 237. | 0. | -6254. | -0.1 | -.000001 | -20287. |
| 11 | 0.00018 | 59.45 | 0.00000 | 6028. | 238. | 0. | -6265. | -0.7 | -.000002 | -22643. |
| 12 | 0.00020 | 46.72 | 0.00000 | 6041. | 238. | 0. | -6278. | -0.3 | -.000002 | -25286. |
| 13 | 0.00022 | 37.74 | 0.00000 | 6055. | 238. | 0. | -6292. | -1.0 | -.000003 | -28243. |
| 14 | 0.00025 | 29.97 | -.00001 | 6079. | 242. | -8. | -6312. | -0.1 | -.000003 | -31443. |
| 15 | 0.00028 | 14.77 | -.00008 | 6224. | 268. | -109. | -6383. | 0.4 | -.000005 | -33995. |
| 16 | 0.00032 | 2.23 | -.00020 | 6470. | 296. | -269. | -6496. | -0.7 | -.000007 | -36442. |
| 17 | 0.00035 | -6.69 | -.00035 | 6806. | 326. | -483. | -6648. | -0.9 | -.000009 | -39119. |
| 18 | 0.00040 | -12.96 | -.00055 | 7231. | 359. | -751. | -6840. | 0.5 | -.000012 | -42153. |
| 19 | 0.00045 | -17.40 | -.00078 | 7745. | 395. | -1072. | -7069. | 0.4 | -.000016 | -45615. |
| 20 | 0.00050 | -20.61 | -.00105 | 8346. | 435. | -1445. | -7336. | 0.3 | -.000020 | -49549. |
| 21 | 0.00056 | -22.97 | -.00136 | 9034. | 480. | -1872. | -7642. | -0.4 | -.000025 | -53987. |
| 22 | 0.00063 | -24.75 | -.00171 | 9811. | 530. | -2354. | -7987. | -0.2 | -.000030 | -58960. |
| 23 | 0.00071 | -26.11 | -.00210 | 10680. | 587. | -2893. | -8372. | -1.0 | -.000036 | -64494. |
| 24 | 0.00079 | -27.79 | -.00266 | 11498. | 645. | -3223. | -8920. | 0.4 | -.000045 | -69683. |
| 25 | 0.00089 | -30.09 | -.00356 | 12094. | 698. | -3223. | -9568. | -0.5 | -.000058 | -73488. |
| 26 | 0.00100 | -32.67 | -.00499 | 12356. | 739. | -3223. | -9872. | 0.3 | -.000077 | -75410. |
| 27 | 0.00112 | -34.65 | -.00682 | 12476. | 774. | -3223. | -10027. | 0.9 | -.000103 | -76502. |
| 28 | 0.00126 | -36.06 | -.00897 | 12528. | 809. | -3223. | -10115. | 0.1 | -.000132 | -77210. |
| 29 | 0.00141 | -37.05 | -.01141 | 12543. | 848. | -3223. | -10168. | 0.6 | -.000166 | -77720. |
| 30 | 0.00158 | -37.76 | -.01411 | 12533. | 893. | -3223. | -10204. | 0.9 | -.000203 | -78121. |
| 31 | 0.00178 | -38.26 | -.01704 | 12639. | 948. | -3360. | -10228. | 0.9 | -.000243 | -79244. |
| 32 | 0.00199 | -38.64 | -.02027 | 12782. | 1012. | -3546. | -10247. | -0.3 | -.000288 | -80600. |
| **33** | **0.00223** | **-38.94** | **-.02388** | **12893.** | **1084.** | **-3716.** | **-10261.** | **0.6** | **-.000338** | **-81787.** |
| 34 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 35 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 36 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 37 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 38 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 39 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |
| 40 | 0.00000 | 0.00 | 0.00000 | 0. | 0. | 0. | 0. | 0.0 | 0.000000 | 0. |

Prestress Tendon Strain on the x-section:

| step | Max. Conc. Strain epscmax | Neutral Axis in. | P/S Steel No. | Strain | Strain No. | Strain | No. | Strain | No. | Strain | No. | Strain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | -.00001 | -41.50 | 1 | -.005644 | | | | | | | | |
| 1 | -.00001 | -42.26 | 1 | -.005644 | | | | | | | | |
| 2 | -.00001 | -43.05 | 1 | -.005645 | | | | | | | | |
| 3 | -.00000 | -43.86 | 1 | -.005646 | | | | | | | | |
| 4 | -.00000 | -44.70 | 1 | -.005647 | | | | | | | | |
| 5 | 0.00000 | -45.56 | 1 | -.005648 | | | | | | | | |
| 6 | 0.00010 | 9055.25 | 1 | -.005701 | | | | | | | | |
| 7 | 0.00011 | 362.50 | 1 | -.005708 | | | | | | | | |

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| | | | | |
|---|---|---|---|---|
| 22 | 0.00063 | -24.75 | 1 | -.007321 |
| 23 | 0.00071 | -26.11 | 1 | -.007674 |
| 24 | 0.00079 | -27.79 | 1 | -.008176 |
| 25 | 0.00089 | -30.09 | 1 | -.008996 |
| 26 | 0.00100 | -32.67 | 1 | -.010301 |
| 27 | 0.00112 | -34.65 | 1 | -.011970 |
| 28 | 0.00126 | -36.06 | 1 | -.013932 |
| 29 | 0.00141 | -37.05 | 1 | -.016152 |
| 30 | 0.00158 | -37.76 | 1 | -.018616 |

```
31 0.00178  -38.26  1 -.021292
32 0.00199  -38.64  1 -.024243
33 0.00223  -38.94  1 -.027534
34 0.00000    0.00  1 -.005801
35 0.00000    0.00  1 -.005801
36 0.00000    0.00  1 -.005801
37 0.00000    0.00  1 -.005801
38 0.00000    0.00  1 -.005801
39 0.00000    0.00  1 -.005801
40 0.00000    0.00  1 -.005801


Recommended value of 'effective moment of inertia' based on
     initial slope of moment-curvature diagram (ft^4) = 211.8303

Yield pt. is defined as the First mild steel yields.
The first mild steel yields between the following Steps:    23  and     24
The computation of mild steel yield point IS within 2% tolerance.
The first P/S steel yields between the following Steps:    24  and     25
The computation of P/S steel yield point IS NOT within 2% tolerance.

              Curvature(rad/in)      Moments (ft-K)
Yield              0.000040           67871
Nominal           See force equilibrium table at concrete strain of .003
Ultimate           0.000000               0


end
```

# APPENDIX – W

(Partial xSECTION output Including Transverse Overturning Effects – Compression Column)

```
05/31/2006, 23:21
************************************************************
*                                                          *
*                       xSECTION                           *
*                                                          *
*               DUCTILITY and STRENGTH of                  *
*     Circular, Semi-Circular, full and partial Rings,     *
*  Rectangular, T-, I-, Hammer head, Octagonal, Polygons   *
*      or any combination of above shapes forming          *
*         Concrete Sections using Fiber Models             *
*                                                          *
* VER._2.40,_MAR-14-99                                     *
*                                                          *
* Copyright (C) 1994, 1995, 1999 By Mark Seyed Mahan.      *
*                                                          *
* A proper license must be obtained to use this software.  *
* For GOVERNMENT work call 916-227-8404, otherwise leave a *
* message at 530-756-2367. The author makes no expressed or*
* implied warranty of any kind with regard to this program.*
* In no event shall the author be held liable for          *
* incidental or consequential damages arising out of the   *
* use of this program.                                     *
*                                                          *
************************************************************
This output was generated by running:
xSECTION
VER._2.40,_MAR-14-99
LICENSE    (choices: LIMITED/UNLIMITED)
UNLIMITED
ENTITY     (choices: GOVERNMENT/CONSULTANT)
Government
NAME_OF_FIRM
Caltrans
BRIDGE_NAME
EXAMPLE
BRIDGE_NUMBER
99-9999
JOB_TITLE
PROTYPE BRIDGE - BRIDGE DESIGN ACADEMY



Concrete Type Information:

     ----------strains--------  --------strength--------
Type   e0    e2    ecc     eu     f0    f2    fcc    fu    E    W
 1 0.0020 0.0040 0.0055 0.0145  5.28  6.98  7.15  6.11  4313   148
 2 0.0020 0.0040 0.0020 0.0050  5.28  3.61  5.28  2.64  4313   148


Steel Type Information:

     -----strains------  --strength-
Type  ey     eh     eu    fy    fu    E
 1 0.0023 0.0150 0.0900 68.00 95.00 29000
 2 0.0023 0.0075 0.0600 68.00 95.00 29000


-----------------------------------
-----------------------------------
-----------------------------------

Force Equilibrium Condition of the x-section:

     Max.             Max.
     Conc.    Neutral Steel           Steel
```

| step | Strain epscmax | Axis in. | Strain Tens. | Conc. Comp. | force Comp. | force Tens. | P/S force | Net force | Curvature rad/in | Moment (K-ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00000 | 0.00 | 0.0000 | 0 | 0 | 0 | 0 | 0.00 | 0.000000 | 0 |
| 1 | 0.00029 | -29.19 | 0.0000 | 2256 | 222 | -2 | 0 | 1.88 | 0.000004 | 2346 |
| 2 | 0.00032 | -23.84 | 0.0000 | 2255 | 228 | -11 | 0 | -2.06 | 0.000005 | 2726 |
| 3 | 0.00035 | -19.33 | -0.0001 | 2264 | 237 | -26 | 0 | -0.29 | 0.000006 | 3094 |
| 4 | 0.00039 | -15.36 | -0.0001 | 2275 | 246 | -47 | 0 | -0.08 | 0.000008 | 3457 |
| 5 | 0.00043 | -11.84 | -0.0002 | 2291 | 258 | -76 | 0 | -1.19 | 0.000009 | 3820 |
| 6 | 0.00048 | -8.79 | -0.0002 | 2317 | 271 | -112 | 0 | 1.96 | 0.000011 | 4189 |
| 7 | 0.00053 | -6.03 | -0.0003 | 2347 | 286 | -157 | 0 | 2.28 | 0.000013 | 4569 |
| 8 | 0.00059 | -3.59 | -0.0004 | 2383 | 302 | -212 | 0 | -0.48 | 0.000015 | 4967 |
| 9 | 0.00065 | -1.45 | -0.0005 | 2431 | 319 | -277 | 0 | -0.18 | 0.000017 | 5390 |
| 10 | 0.00072 | 0.46 | -0.0006 | 2490 | 338 | -354 | 0 | 0.01 | 0.000020 | 5841 |
| 11 | 0.00079 | 2.09 | -0.0008 | 2557 | 362 | -445 | 0 | 0.31 | 0.000023 | 6331 |
| 12 | 0.00087 | 3.60 | -0.0010 | 2637 | 387 | -552 | 0 | -1.88 | 0.000027 | 6859 |
| 13 | 0.00097 | 4.88 | -0.0011 | 2732 | 414 | -672 | 0 | 0.84 | 0.000031 | 7435 |
| 14 | 0.00107 | 6.00 | -0.0013 | 2836 | 444 | -807 | 0 | -0.59 | 0.000036 | 8061 |
| 15 | 0.00118 | 6.94 | -0.0016 | 2954 | 477 | -956 | 0 | 0.74 | 0.000041 | 8740 |
| 16 | 0.00131 | 7.76 | -0.0018 | 3083 | 513 | -1123 | 0 | 0.17 | 0.000046 | 9477 |
| 17 | 0.00144 | 8.49 | -0.0021 | 3230 | 558 | -1314 | 0 | -0.45 | 0.000053 | 10276 |
| 18 | 0.00160 | 9.12 | -0.0024 | 3389 | 607 | -1519 | 0 | 2.42 | 0.000059 | 11119 |
| 19 | 0.00176 | 9.96 | -0.0028 | 3497 | 655 | -1677 | 0 | 1.32 | 0.000068 | 11722 |
| 20 | 0.00195 | 10.82 | -0.0033 | 3579 | 706 | -1812 | 0 | -1.62 | 0.000078 | 12213 |
| 21 | 0.00216 | 11.66 | -0.0038 | 3650 | 758 | -1935 | 0 | -0.48 | 0.000089 | 12638 |
| 22 | 0.00238 | 12.54 | -0.0045 | 3692 | 811 | -2029 | 0 | 0.16 | 0.000102 | 12957 |
| 23 | 0.00264 | 13.30 | -0.0052 | 3731 | 869 | -2124 | 0 | 2.31 | 0.000116 | 13266 |
| 24 | 0.00291 | 14.11 | -0.0061 | 3742 | 926 | -2194 | 0 | 0.52 | 0.000133 | 13492 |
| 25 | 0.00322 | 14.74 | -0.0070 | 3778 | 963 | -2268 | 0 | -1.28 | 0.000152 | 13683 |
| 26 | 0.00356 | 15.28 | -0.0081 | 3813 | 991 | -2330 | 0 | 0.34 | 0.000172 | 13834 |
| 27 | 0.00394 | 15.73 | -0.0092 | 3856 | 1018 | -2399 | 0 | 0.71 | 0.000194 | 14012 |
| 28 | 0.00435 | 16.07 | -0.0104 | 3904 | 1049 | -2478 | 0 | 0.63 | 0.000219 | 14204 |
| 29 | 0.00481 | 16.24 | -0.0117 | 3950 | 1075 | -2552 | 0 | -0.48 | 0.000244 | 14332 |
| 30 | 0.00532 | 16.23 | -0.0129 | 4008 | 1092 | -2623 | 0 | 1.90 | 0.000269 | 14424 |
| 31 | 0.00588 | 16.38 | -0.0144 | 4043 | 1106 | -2675 | 0 | -0.34 | 0.000300 | 14544 |
| 32 | 0.00650 | 16.52 | -0.0161 | 4089 | 1121 | -2734 | 0 | 1.91 | 0.000334 | 14706 |
| 33 | 0.00718 | 16.66 | -0.0180 | 4135 | 1137 | -2797 | 0 | 0.76 | 0.000372 | 14879 |
| 34 | 0.00794 | 16.77 | -0.0200 | 4180 | 1156 | **-2862** | 0 | 0.35 | 0.000414 | **15055** |
| 35 | 0.00878 | 16.86 | -0.0223 | 4226 | 1177 | -2928 | 0 | 1.07 | 0.000459 | 15231 |
| 36 | 0.00971 | 16.91 | -0.0248 | 4271 | 1201 | -2997 | 0 | 0.93 | 0.000509 | 15403 |
| 37 | 0.01073 | 16.97 | -0.0275 | 4310 | 1231 | -3069 | 0 | -2.02 | 0.000565 | 15573 |
| 38 | 0.01186 | 16.96 | -0.0304 | 4366 | 1242 | -3132 | 0 | 1.47 | 0.000624 | 15730 |
| 39 | 0.01312 | 16.95 | -0.0335 | 4415 | 1255 | -3195 | 0 | 0.47 | 0.000689 | 15869 |
| 40 | 0.01450 | 16.91 | -0.0370 | 4458 | 1269 | -3255 | 0 | -1.79 | 0.000761 | 15987 |

```
First Yield of Rebar Information (not Idealized):

     Rebar Number 20
     Coordinates X and Y (global in.)  -3.85, -31.70
     Yield strain =  0.00230
     Curvature (rad/in)=  0.000057
     Moment (ft-k) =   10802


Cross Section Information:

     Axial Load on Section (kips) =  2474
     Percentage of Main steel in Cross Section =   1.44
     Concrete modulus used in Idealization (ksi) =  4313
     Cracked Moment of Inertia (ft^4) =    25.572


Idealization of Moment-Curvature Curve by Various Methods:


                  Points on Curve        Idealized Values
                  ===============   =============================
```

# APPENDIX – W

(Partial xSECTION output Including Transverse Overturning Effects – Compression Column Continues)

```
Method     Conc.                       Yield         symbol  Plastic
 ID      | Strain  Curv.   Moment | Curv.  Moment   for   Curv.
         | in/in   rad/in  (K-ft) | rad/in (K-ft)  moment rad/in
Strain @ 0.003   0.000138   13546 0.000071   13546   Mn  0.000689
Strain @ 0.004   0.000198   14042 0.000074   14042   Mn  0.000687
Strain @ 0.005   0.000253   14366 0.000075   14366   Mn  0.000685
CALTRANS 0.00755 0.000392   14964 0.000079   14964   Mp  0.000682
UCSD@5phy0.00558 0.000283   14479 0.000076   14479   Mn  0.000685
```