THREE BEARING CONCEPT FOR PRESTRESSED CONCRETE ADJACENT BOX BEAM BRIDGES

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ABSTRACT

The design of bearings for precast prestressed concrete adjacent box beam (ABB) bridges has evolved from simple elastomeric strips, to reinforced elastomeric bearing pads. For bridges with single reinforced bearing pads, problems with torsional rotation have occurred in construction when wide beams are canted along the cross slope of the roadway. To resolve this problem engineers placed two reinforced bearings at each end of the beams. This solved the beam rotation problem, but created problems with adequate seating of the bearings. Inevitably, one bearing would not be loaded due to uneven bridge seats. This paper investigates the concept of designing a bearing arrangement with a three bearing concept. Methods for calculating thermal movements at each end of the beam and a worked design example are presented.

Keywords: Bridges, Bearings

INTRODUCTION

Precast prestressed concrete adjacent box beam (ABB) bridges are used in many states for short to medium span bridges. The most desirable aspects of this type of bridge are rapid construction (a cast-in-place bridge deck is not required) and a shallow bridge cross section. The design and detailing of bearings for ABB bridges range from simple elastomeric strips to steel reinforced elastomeric bearings designed according to the AASHTO design specifications.

The precast concrete industry has pioneered the use of elastomeric bearings for structural supports. The most common design approach for bearings on single span structures is to "float" each beam end on elastomeric bearings. This refers to having an expansion bearing on each end of the beam, and no fixed support on either end. There are a number of benefits to this approach:

1. The magnitude of thermal movement on each end of the beam is half of what would be found on a conventional bridge span with one expansion end and one fixed end. This smaller movement results in smaller bearings.
2. Second, the expansion joints for the bridge will be less expensive due to the smaller movement capacity that will be required.

HISTORY OF BEARINGS ON ADJACENT BOX BEAM BRIDGES

ABB bridges were originally designed using simple elastomeric strips placed across the supports, however the strips would fall out in many cases after several years of service. Regional standards were then developed to require a single steel reinforced elastomeric bearing at each end of each beam, which eliminated the problem with bearings falling out.

There are two basic ways to detail the application of the roadway cross slope for ABB bridges. For narrow roadways with bituminous overlays, the beams are often placed level across the roadway and the pavement is beveled to create the desired cross slope (See Figure 1). However, on wider roadways, and on superelevated structures, the beams are placed on a slope (canted) that is parallel to the roadway cross slope (See Figure 2).

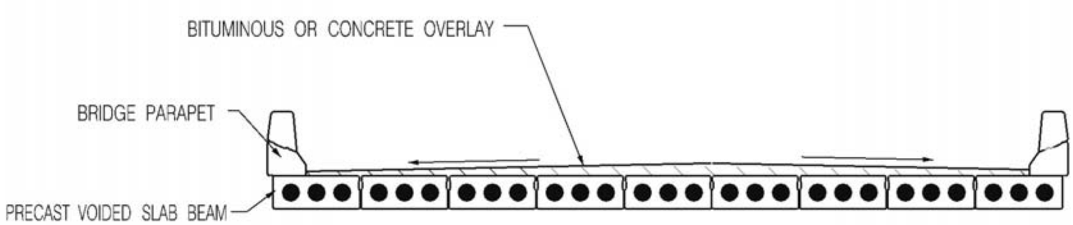

FIGURE 1: NORMAL CROSS SLOPE SECTION WITH FLAT BEAMS

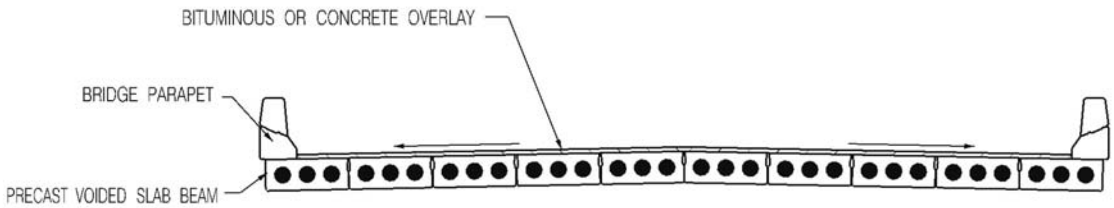

FIGURE 2: NORMAL CROSS SLOPE SECTION WITH CANTED BEAMS

This approach to superstructure layout on ABB bridges has worked well over the years, however several problem have continued to occur. The most common problem is a lack of stability of the precast beams during erection, especially when the beams are placed along the cross slope of the roadway (See Figure 2). The beams will tend to rotate (roll over) as they are placed. This rotation causes problems with the installation of the transverse connection of the beams (either post-tensioning or through bolts) because the rotation causes a misalignment of the holes. In order to prevent this rotation, contractors have had to use timber wedges and shims to keep the beams from moving prior to the installation of the transverse beam connections.

To prevent this problem, the standards were then changed to require two bearings at each end of each beam (See Figure 3). This solved the beam rotation problem, but created problems with adequate seating of the bearings. Inevitably, one bearing would not be loaded, which led to installation of shims and grinding of bearing seats in order to provide uniform bearing on each pad. These processes inevitably led to increases in construction costs and construction time.

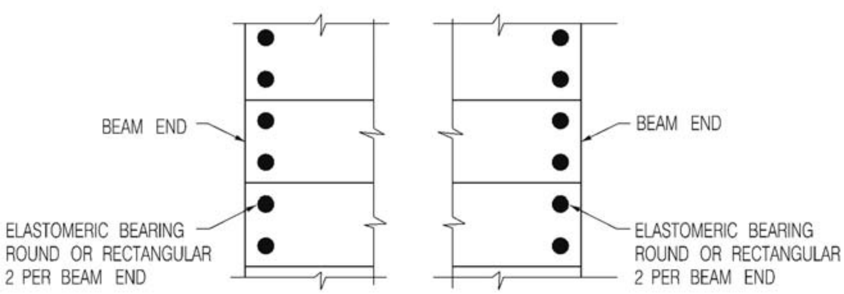

FIGURE 3:
PLAN VIEW OF FOUR BEARING LAYOUT

THREE BEARING CONCEPT

The PCI Northeast Bridge Technical Committee has been working on the standardization of the design and detailing of box beam bridges for the last 15 years. This committee undertook the bearing design concepts that were been previously discussed. This paper will focus on the work of the committee to develop a solution to the problem with bearings on ABB bridges.

The approach that has been developed is a three bearing concept (See Figure 4). The beams would have one bearing on one end, and two on the other end. A tri-pod is the most stable means of supporting a solid object on uneven ground. If there are any minor inconsistencies in the bridge seat, a three bearing concept would properly seat the beam with even distribution of load to each bearing on the two bearing end of the beam. The beam would also be stable during construction, because the beam would essentially be fixed against rotation at one end, and the high torsional stiffness would prevent rotation at the other end.

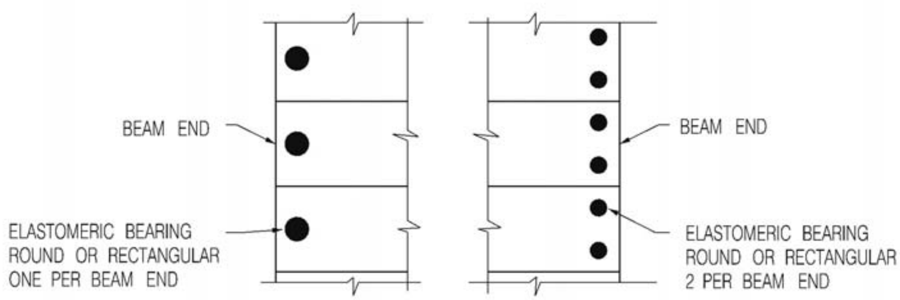

FIGURE 4:
PLAN VIEW OF THREE BEARING LAYOUT

Different bearing configurations were considered such as varying the bearings layout on each beam. This idea was to have one bearing at the first beam end, and then two bearings on the next beam, and one on the third, and so on. This would be the most stable situation for the entire superstructure, but it would cause many problems with design and construction since the double bearings would be a different height than the single bearings. For this reason, the bearing layout shown in Figure 4 is recommended.

The challenge for the implementation of this concept is in the design of the bearings. The bearings at the end of the beam that has two bearings would be more lightly loaded, and inevitably be smaller in size than the single end bearing. If all bearings were made the same, the fact that two bearings are present at one end of the beam would still mean that the double bearing end would be much stiffer in resisting thermal movement than the single bearing end. This variation in bearing stiffness brings about the need for a different design process than what is followed for beams with equal bearings at each end. The following sections of this paper will discuss the current design practice, and the proposed design practice for the three bearing concept.

CURRENT DESIGN PRACTICE FOR EQUAL EXPANSION BEARINGS AT EACH END OF THE BEAM

The basic premise of a floating beam design is that the bearings on each end of the beam have equal stiffness. Figure 5 depicts an idealized model of a floating beam with the same stiffness bearings at each end. The term Δ_s refers to the amount of thermal movement at the bearings. The term K refers to the longitudinal stiffness of the bearings subjected to the shear deformation Δ_s.

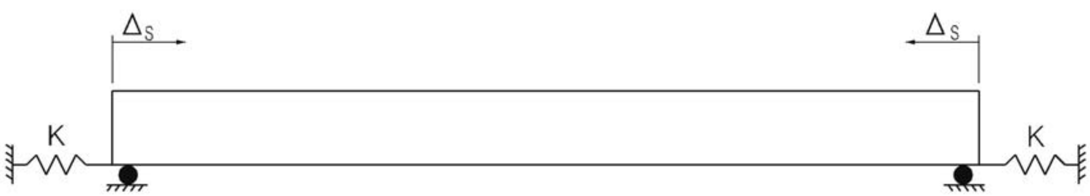

FIGURE 5: FLOATING BRIDGE MODEL WITH EQUAL BEARINGS

The AASHTO specifications[1,2] define the maximum longitudinal force in an elastomeric bearing subjected to a horizontal shear deformation as:

$$H = G*A*\Delta_s / h_{rt} \quad \text{(kips)} \qquad (1)$$

(AASHTO Eq. 14.5.3.1-2)[1]
(Similar to AASHTO LRFD Eq. 14.6.3.1-2)[2]

Where
- G = Shear modulus of the elastomer (ksi)
- A = Plan area of the bearing (in^2)
- Δ_s = Shear deformation of the bearing (in)
- h_{rt} = Total thickness of elastomer (in)

The total thermal movement Δ_T of a beam is determined by the following equation:

$$\Delta_T = \alpha*L*\Delta_{temp} \quad \text{(inches)} \qquad (2)$$

Where
- α = Coefficient of Thermal Expansion ($6.0x10^{-6}$ for concrete)
- L = Length of element under consideration (inches) (span length for calculating total thermal movement)
- Δ_{temp} = Temperature differential (degrees Fahrenheit)

A spring coefficient (K) can be calculated for each bearing as follows:

$$K = H / \Delta_s \quad \text{(kips/inch)} \qquad (3)$$

Substituting Equation 1 into Equation 3 yields the following:

$$K = G^*A / h_{rt} \qquad \text{(kips/inch)} \qquad (4)$$

By applying the thermal movement to the model with equal springs at each end, it can easily be concluded via symmetry that the thermal movement at each bearing is equal. This is the basic premise of current design practice.

RECOMMENDED DESIGN PRACTICE FOR UNEQUAL EXPANSION BEARINGS AT EACH END OF THE BEAM

Figure 6 depicts an idealized model of a beam that has different bearings at each end. This would be the case for a beam with two bearings on one end, and one bearing on the other end. The total thermal movement of the beam (Δ_T) would be the same as the previous model, however the amount of thermal movement at each end (Δ_1 and Δ_2) would not be the same because of the un-symmetric stiffness of the supports (K_1 and K_2).

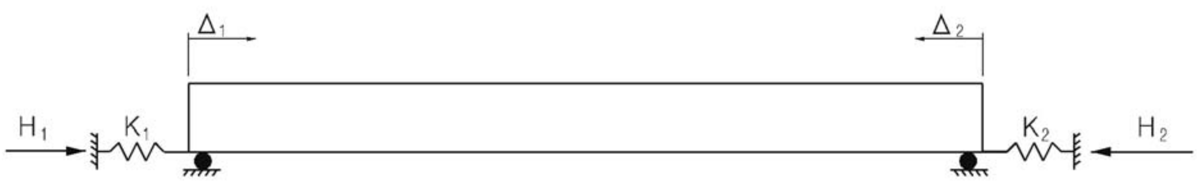

FIGURE 6: FLOATING BRIDGE MODEL WITH UNEQUAL BEARINGS

The calculation of the thermal movement at each end of the beam is not a simple one to solve because there are quite a few unknowns. They are as follows:

- The size of the bearings is not known because the thermal movement is needed in the design of the bearing. Therefore the terms K_1 and K_2 are unknown.
- The amount of thermal movement is not known because the amount of movement at each end is a function of the stiffness of the bearing. Therefore the terms Δ_1 and Δ_2 are unknown.

The following is a derivation of the amount of thermal movement at each end of the beam:

Step 1: $\sum F_x = 0$

$$H_1 = H_2$$

Spring Force: $H = \Delta * K$

Therefore: $\Delta_1 * K_1 = \Delta_2 * K_2$

Solving for: $\Delta_1 = \Delta_2 * (K_2/ K_1)$ (5)

Step 2: $\sum$Movement = 0

$\Delta_T = \Delta_1 + \Delta_2$

Solving for: $\Delta_1 = \Delta_T - \Delta_2$ (6)

Step 3: Substitute Equation 6 into Equation 5 yields:

$\Delta_1 = \Delta_T [(K_2/ K_1) / (1 + K_2/ K_1)]$ (7)

Then Use Equation 2 to solve for Δ_2

Since the four unknowns (Δ_1 , Δ_2 , K_1 , and K_2) are interrelated, the solution is best derived via trial and error approach. The recommended procedure is as follows:

A. Assume the thermal movement at each bearing as a percentage of the total beam thermal movement. A recommended value is to assume that 60 percent of the total movement takes place at the end with the single bearings, and 40 percent of the movement takes place at the end with the double bearings.
B. The single bearing will support the total end reaction at its end.
C. The double bearings will support ½ the total reaction at their end.
D. The bearings can then be designed according to the AASHTO specifications.
E. Once the bearings are designed, then the amount of movement at one end can then be determined using Equation 7. The movement at the other end can be determined by using Equation 6.
F. If the amount of movement is different that what was assumed in Step A, then repeat steps B through E using the movement calculated in step E. Continue this process until the terms Δ_1 and Δ_2 converge from one cycle to the next.

Trial designs using this process have converged within one or two cycles. The reason for this is that small variations in the thermal movement at each bearing has little effect on the overall design of the bearing. The key to minimizing the number of design cycles is to start at a reasonable assumption of the initial thermal movement at each bearing. The experience of the author is that assuming 35 to 40 percent of the total movement at the double bearing end is a good starting point.

DESIGN EXAMPLE
GIVENS:

Span Length: 80 feet
Temperature Range: 45 degrees F (variation from installation temperature)
Note: Refer to current State D.O.T. design practices for local design temperature ranges
Dead Load Reaction: 41.1 kips
Live Load Reaction: 39.6 kips
Use Round Bearings

CALCULATE TOTAL THERMAL MOVEMENT

$\Delta_T = \alpha * L * \Delta_{temp}$

α = Coefficient of Thermal Expansion = $6.0x10^{-6}$ for concrete
L = Span Length = 960 inches
Δ_{temp} = Temperature differential = 45 degrees F

$\Delta_T = 0.260$ inches

ASSUME THAT 40 % OF TOTAL MOVEMENT GOES TO DOUBLE BEARING END:

$\Delta_1 = 0.6 * 0.260 = 0.156$ inches (Subscript 1 refers to the single bearing end)
$\Delta_2 = 0.4*0.260 = 0.104$ inches (Subscript 2 refers to the double bearing end)

DESIGN SINGLE BEARINGS USING FULL END REACTION:

Note: Calculations not shown for brevity

Results:

Bearing Dimensions: 12” diameter, 2.90” total thickness
Total Elastomer Thickness = h_{rt} = 2.30 inches
Shear Force in Bearing: H = 1.53 kips/bearing
Spring Coefficient: $K = H / \Delta_s = 1.53 / 0.156 = 9.81$ kips/inch

DESIGN DOUBLE BEARINGS USING ½ END REACTION:

Note: Calculations not shown for brevity

Results:

Bearing Dimensions: 8” diameter, 1.678” total thickness
Total Elastomer Thickness = h_{rt} = 1.20 inches
Shear Force in Bearing: H = 0.87 kips/ bearing
Spring Coefficient: $K = H / \Delta_s = 0.87 / 0.104 = 8.4$ kips/inch

CALCULATE SPRING COEFFICIENTS AT EACH BEAM END:

Double Bearing End: $K_2 = 2 * 8.4 = 16.8$ kips/inch
Factor of 2 is to account for 2 bearings
Single Bearing End: $K_1 = 1 * 9.81 = 9.81$ kips/inch

CALCULATE MOVEMENT AT BEARINGS BASED ON SPRING COEFFICIENTS:

$\Delta_1 = \Delta_T [(K_2/ K_1) / (1 + K_2/ K_1)]$ (using Eq. 7)

$\Delta_1 = 0.260 [(16.8/9.81) / (1 + 16.8/9.81)] = 0.164$ inches

$\Delta_2 = 0.260 – 0.164 = 0.096$ inches (using Eq.6)

Table 1: Intermediate Results

Location	**Assumed Movement**	**Calculated Movement**
Single Bearing End	0.156 inches	0.164 inches
Double Bearing End	0.104 inches	0.096 inches

This design was then repeated using the calculated movements. The actual bearing design did not change. The second cycle converged as follows:

Table 2: Final Results

Location	**Assumed Movement**	**Calculated Movement**
Single Bearing End	0.164 inches	0.163 inches
Double Bearing End	0.096 inches	0.096 inches

CONCLUSIONS

The stability of a precast concrete box section has been a problem during construction, especially when the beams are canted. Methods to solve this problem have included the use of continuous strip bearings and four bearings arrangements (two at each end of each beam). The strip bearings have been found to “walk out” over time. This is due to the fact that most strip bearings do not meet the design criteria that is outlined in the AASHTO Specifications. The four bearing concept can be designed to meet the AASHTO criteria, however in practice, it is virtually impossible to obtain uniform vertical load at each bearing. This brings about the high probability that one or more of the bearings would “walk out” due to fact that the bearing is not properly loaded. There is also a possibility that bearings could fail due to overload.

The three bearing approach can solve these problems. A solid element supported at three points is determinant, therefore the load in each bearing can be accurately calculated. This will also provide a stable piece during construction. The design of an unsymmetrical bearing arrangement requires a design that accounts for the variable stiffness of the bearing elements at each end of the beam. An approach has been developed using basic principles of statics and mechanics of materials. The recommended approach is to assume that 40 percent of the total thermal movement occurs at the double bearing end, and 60 percent of the total thermal movement occurs at the single bearing end. From this assumption, a trial and error design process can be followed that will converge in a few cycles.

REFERENCES

1. *AASHTO (1996). Standard Specifications for Highway Bridges*, 16th Ed., Chapter 14, Washington, D.C.
2. *AASHTO (1998). LRFD Highway Bridge Design Specifications,* 2nd Ed., Chapter 14, Washington, D.C.