INTEGRAL ABUTMENT BRIDGES - CONCRETE VS. STEEL SUPERSTRUCTURES

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ABSTRACT

Integral abutment bridges eliminate expansion joints, reduce the initial construction cost and also bridge life cycle cost. With added structural redundancy and increased seismic resistance, the integral abutment bridge is generally preferred, provided that the limitations detailed in state DOTs' Bridge Manual are satisfied.

Integral abutment bridges are subject to temperature induced displacements. What are the advantages and challenges of using concrete superstructures on integral abutment bridges compared to steel superstructures? How far can the empirical limits be stretched?

Although numerous researches have been performed in different states and universities, the current design criteria for integral abutment bridges are mainly based on each state's past experience and confidence in the field performance. From state to state, there is a wide range of design policies, methodology, criteria and detailing of integral abutment bridges.

Through extensive examination of research literature and two recent integral abutment bridge design projects – one with a concrete superstructure and the other with a steel superstructure, the authors investigated the design and detailing issues such as temperature range, secondary stress on superstructure due to restraints, as well as the influence of creep and shrinkage. It is the authors' intention to contribute to the development of design procedures for integral abutment bridges.

Keywords: Integral abutment bridges, Temperature range, Continuity

INTRODUCTION

Although long span suspension and cable stay bridges are magnificent and exciting, the majority of bridges have short or medium spans. A 2004 bridge study sponsored by Portland Cement Association (PCA) and conducted by the author indicates that more than 95% of bridges in the United States have span lengths less than 300 feet. Decisions made during the design stage on design philosophy, methodology and detailing of these bridges have a great impact on bridge performance, initial construction cost and life cycle cost.

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Field inspections show that the typical condition of an expansion joint is either being filled with debris or being broken (see Figure 1). Leaking joints allow water containing deicing salts to drain to the superstructure. This is the major cause of bearing devise damage, beam corrosion, deterioration of underside of deck and substructure. Broken joints are also hazardous to traffic.

The expansion joints are expensive to maintain and more expensive to replace. Generally, expansion joints need to be cleaned several times a year and to be repaired or even replaced in one-third or one-half of the bridge's life span. The repair or replacement of expansion joints is not only a labor intensive procedure, but it is also a procedure that involves traffic disruption and has an impact on the public.

Joint Filled with Debris

Broken Joint

Figure 1 Problems Associated with Joints
(Picture courtesy of PB inspection team)

Integral abutment bridges eliminate expansion joints, reduce the initial construction cost and bridge life cycle cost. Integral abutments require less form work and broaden construction tolerance, thus accelerating the construction phase. In the long-term perspective, integral abutment bridges are virtually maintenance-free, therefore reducing the life cycle cost significantly.

Structurally, integral abutment bridges add structural redundancy and enhance seismic resistance. Beams are unlikely to be shaken off from beam seats in an earthquake. In addition, integral abutments provide more flexibility for span arrangements and reduce the bridge length driven by mitigation of excessive uplifting forces.

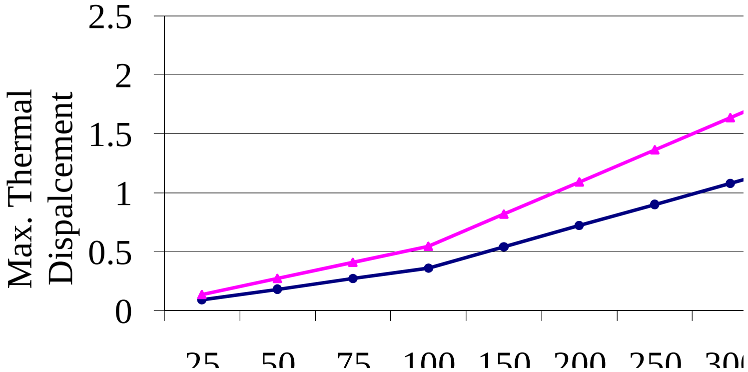
INTEGRAL ABUTMENT BRIDGES WITH CONCRETE SUPERSTRUCTURES - ADVANTAGES AND CHALLENGES

Advantages

Integral abutment bridges are subject to temperature induced displacements. These displacements change their magnitudes and directions, not only seasonally, but also on a daily basis. The components of an integral abutment bridge have to be designed for these thermal deformations and stresses.

Due to the difference in effective temperature range and the coefficient of thermal expansion, the total thermal movement per hundred feet of an expansion length, with concrete girders, is 30% to 50% less than a bridge with steel girders. In other words, a bridge with concrete girders can be built 30% to 50% longer than one with steel girders if the same amount of thermal displacement is limited.

Compared to ones with steel girders, bridges with concrete girders have smaller temperature range and thermal expansion coefficient. According to AASHTO LRFD Bridge Design Specification 4th Edition, in cold climates, temperature range for concrete structures is from 0^{o}F to 80^{o}F, while for steel structures it is from -30^{o}F to 120^{o}F. Assume a construction temperature of 50^{o}F, and a thermal expansion coefficient of 6.0×10^{-6} for steel; 6.5×10^{-6} for concrete. The maximum thermal displacement per one hundred feet of expansion length is 0.36” and 0.55” for concrete and steel structures, respectively. It is shown that the maximum thermal movement for concrete structures is 53% less than that for steel structures.



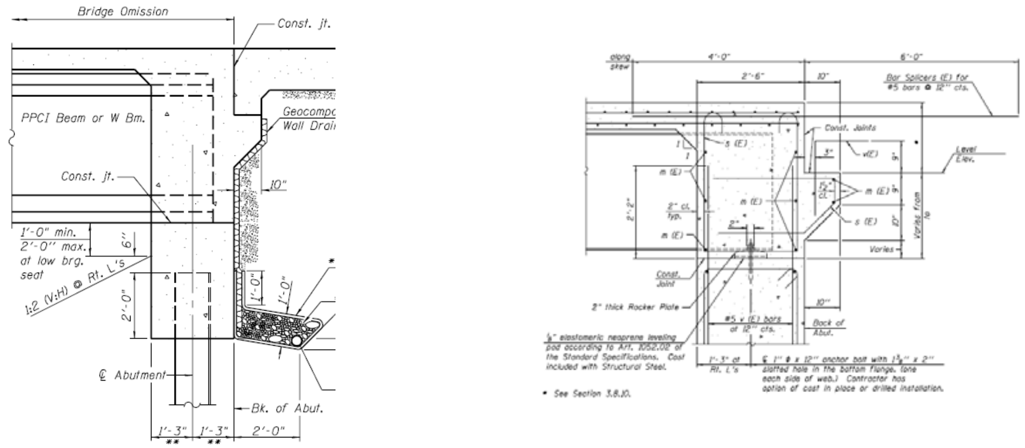
Design, Detailing and Construction

Concrete girders are typically designed as simple span for dead loads and continuous for composite dead loads and traffic live loads. The continuity is provided through the top reinforcement in the deck slab and the extension of prestressing strands into the diaphragm over the intermediate support. The concrete diaphragm detail is usually standardized and does not require a great deal of design and detailing efforts. Field work is relatively straightforward and can be incorporated with deck concrete work.

On the contrary, steel girders are usually designed as continuous over the intermediate piers. Steel segments are spliced near the dead load contraflexure points. Splice design, detailing and assembling are tedious jobs, not to mention time consuming. Field splices also increase steel and labor cost considerably. For this reason, some designers have begun emulating the similar details of simple beam made continuous with a concrete diaphragm over the pier to steel girder details (Azizinamini) (Lampe).

At integral abutments, concrete girders are typically supported directly on the abutment pile cap with elastomeric pads. Bearing devices and installation of the bearings are eliminated (see Figure 3).

Steel girders however, require a fixed type of bearings to be supported on the concrete pile cap. The bearings and steel end diaphragms are then embedded in the concrete end diaphragm (also see Figure 3).



with PPC I-Girder with Steel Girder

Figure 3 Typical Section Through Integral Abutment (IDOT)

Challenges and Issues

Simply supported prestressed beams tend to deform upwards due to creep and shrinkage. There are no restraint moments at supports. If the beams are continuous over the supports, the positive moments will develop at the restrained support as a result of creep and shrinkage. The stresses produced by the positive secondary moments are resisted by the positive reinforcement in the diaphragm.

“The more the better” is not always true, as in the case of providing positive moment capacity at the diaphragm. If the positive moment capacity is less than the secondary moment induced stress, the bottom of the diaphragm concrete will crack, thus the stress will be relieved. If excessive positive moment capacity is provided in the diaphragm, cracks will develop in the girder instead of in the diaphragm (Oesterle et al., 2004). Oesterle suggests that in the long term, the total continuity for maximum positive moment (dead plus live loads and secondary moments) in mid-span of the concrete beam does not benefit from negative moment continuity over the intermediate pier. Oesterle recommends to not provide any positive continuity moment reinforcement at the piers, and detail the girder to diaphragm interface to allow relative movement and provide crack control joint.

Another option Oesterle provided is to design the positive moment capacity at the diaphragm to act as a fuse. The fuse, in turn, will yield prior to developing 125% allowable tensile stress in the bottom of the girder near mid-span under secondary forces and dead plus live loads.

Many states specify shop bent of prestressing strands to hook into the cast-in-place diaphragm in order to provide positive moment capacity (Figure 4), while other states detail the diaphragm over pier without positive moment reinforcement (Figure 5).

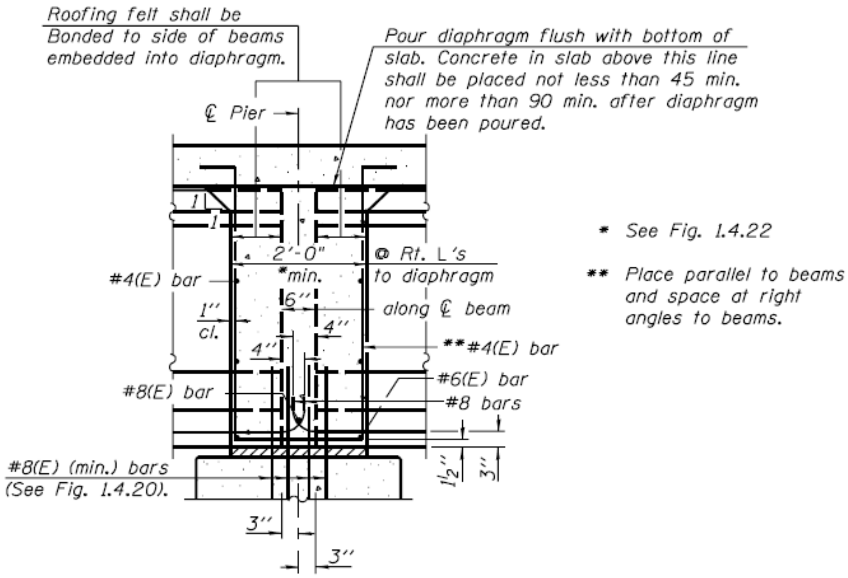


Figure 4 Diaphragm with Positive Moment Capacity (IDOT)

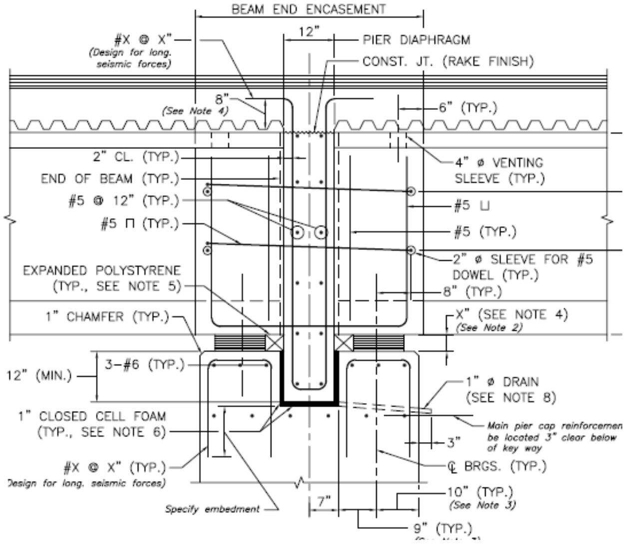


Figure 5 Diaphragm without Positive Moment Capacity (MassHwy)

SUMMARY

Integral abutment bridges are subject to temperature induced displacements. Compared to steel structures, concrete bridges have their advantages and challenges. It is important to incorporate research findings and field experiences into design practices and establish consistent design guidelines and procedures when bridges fall outside of empirical limits.

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