INTEGRAL ABUTMENT and JOINTLESS BRIDGES DESIGN ISSUES and RECOMMENDATIONS

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ABSTRACT

Before the 1960s, almost all bridges in the U.S. were built with expansion joints. These expansion joints often did not perform as well as intended. They required considerable maintenance, which undermined the economical operation of the bridges. Accident and vehicle damage caused by defective expansion joints raised safety concerns. Starting in the early 1960s, the use of jointless bridges for new bridge construction attracted widespread interest recently.

A survey in using of designing integral abutment and jointless bridges in the US highways was performed in 2004, and a workshop was held to discuss this survey. The survey was divided into different topic areas which included General Issues, Design and Details, Foundation, Abutment/Backfill, Approach Slabs, Retrofit (Jointed to Jointless), and Other Issues. This paper discusses the survey results, design issue concerned and mitigations measures recommended; and presents some of the important features of integral abutment and jointless bridge design and some guidelines to achieve improved design.

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INTRODUCTION

Before the 1960s, almost all bridges in the U.S. were built with expansion joints. These expansion joints often did not perform as well as intended. They required considerable maintenance, which undermined the economical operation of the bridges. Accident and vehicle damage caused by defective expansion joints raised safety concerns. Starting in the early 1960s, the use of jointless bridges for new bridge construction attracted widespread interest recently.

The advantages of using integral abutments and jointless bridges has been listed and discussed by many researchers and practitioners. Although merits of eliminating expansion joints to solve maintenance problems and connection issues (such as prevention of superstructure falling from large ground movements during earthquakes), there are some concerns of using the integral abutment in practices.

The Federal Highway Administration (FHWA) worked together with AASHTO and performed a survey in using of designing integral abutment and jointless bridges (references name), and held a workshop to discuss this survey. One of the workshop papers summarizes the responses received to date from the states. The survey was divided into different topic areas which included General Issues, Design and Details, Foundation, Abutment/Backfill, Approach Slabs, Retrofit (Jointed to Jointless), and Other Issues. Integral Abutments, as defined in the survey and in this paper, refers to the monolithic construction of the abutment with the deck in order to eliminate the joints at the end of the bridge. This includes the use of Full, Semi Integral Abutments and Deck Extensions. Jointless bridges refers to the elimination of joints at the piers through the usage of integral pier caps, continuous spans and continuous for live load construction. This paper extracts the survey results, design issue concerned and mitigations measures recommended.

IAJB SURVEY RESULTS

Survey conducted in 2004, and according to the responses, there are approximately 13000 integral abutment (IA) bridges, of which approximately 9000 are full integral abutment bridges, approximately 4000 are semi-integral abutment bridges and approximately 3900 deck extension bridges in-service. The increase in the number of integral abutments from the numbers reported in the 1995 survey can be attributed to the acceptability of the benefits of integral abutments, familiarity with design and construction issues and a larger sample of responding states (39 respondents in 2004 versus 18 in 1995). The numbers reported are approximate since the National Bridge Inventory (NBI) data, which is kept by all the states with information about their bridges, does not differentiate between the different types of abutments and most states do not have other methods for maintaining an inventory bridges and/or integral abutments.

General Issues

The responses to General Questions regarding the states' criteria for using integral abutments, show that a majority of the states do not limit the maximum span within the bridge, but do limit the total length of the bridge and the skew of the bridge. Table 1 summarizes the criteria range provided by the states for prestressed concrete girder and steel bridges for maximum span, total length of bridge, maximum skew of bridge and maximum curvature.

TABLE 1. RANGE OF DESIGN CRITERAI USED FOR SELECIONT OF INTEGRAL ABUTENTSMs.

PRESTRESSED CONCRETE GIRDERS	RANGE
MAXIMUM SPAN	
Full Integral	60 – 200
Semi Integral	90 – 200
Deck extensions	90 – 200
Integral Piers	120 – 200
TOTAL LENGTH	
Full Integral	150 – 1175
Semi Integral	90 – 3280
Deck extensions	200 – 750
Integral Piers	300 – 400
MAXIMUM SKEW	
Full Integral	15 – 70
Semi Integral	20 – 45
Deck extensions	20 – 45
Integral Piers	15 – 80
MAXIMUM CURVATURE	
Full Integral	0 – 10
Semi Integral	0 – 10
Deck extensions	0 – 10
Integral Piers	3 - No Limit

STEEL GIRDERS	RANGE
MAXIMUM SPAN	
Full Integral	65 - 300
Semi Integral	65 - 200
Deck extensions	80 - 200
Integral Piers	100 - 300
TOTAL LENGTH	
Full Integral	150 - 650
Semi Integral	90 - 500
Deck extensions	200 - 450
Integral Piers	150 - 1000
MAXIMUM SKEW	
Full Integral	15 - 70
Semi Integral	30 - 40
Deck extensions	20 - 45
Integral Piers	15-No Limit
MAXIMUM CURVATURE	
Full Integral	0 - 10
Semi Integral	0 - 10
Deck extensions	0 - 10
Integral Piers	0 - No Limit

The utilization of integral abutments with curved bridges is not widely accepted based on survey responses. Four states reported that they allow the use of curved girder bridges with integral abutments and three more allow the construction of curved bridges with straight girders and integral abutments. An alternative mentioned to account the forces in curved bridges and/or long bridges is the use of integral abutments with an expansion joint elsewhere on the bridge.

Design and Detail

Regarding the design and details on the states' future plans for jointless bridge construction, including the future use of integral abutments, continuous spans, retrofit of existing bridges, and policy about elimination of joints, the result revealed that over ninety percent (90%) of the states have a policy to eliminate as many joints as possible and construct jointless simple and continuous span bridges whenever possible. However, only 77% indicated that they will design integral (fully and semi) abutments whenever possible and 79% noted that they will design bridges as jointless whenever they meet the design criteria for jointless bridges (Figure 4). The difference in the percentages between eliminating as many joints as possible (92%) and using integral abutments whenever possible (77%) can be attributed to states that do not extensively use chemicals for deicing of bridges in the winter and therefore do not have a policy of incorporating integral abutments in their bridge design.

Noteworthy comments about problems with multiple-span jointless bridges, integral abutment approach slabs, scourability issues and transfer of seismic forces into the substructure issues has caused some bridge owners not to use this type of bridges or change to using semi-integral type abutments because they are more economical in seismic zones.

Majority of survey have dealt with forces, including passive and active earth pressure, temperature, creep, shrinkage, settlement, additional loads due to skew layout, additional forces due to curvature and other forces that states account for in the design of integral abutments. The survey revealed that 72% of the states account for temperature related forces. In addition, states also noted that they account for temperature (temperature gradient, thermal expansion and contraction in longitudinal and transverse direction) in their design, but the procedure for accounting for the thermal expansion and contraction varied widely.

The results also indicate that 59% of the states surveyed accounted for passive earth pressures, but only 21% of the states allow for curved bridges with integral abutments and account for the additional forces due to the curvature of the bridge.

Noteworthy comments about design of integral abutments include Illinois' practice to designed only for vertical loads, North Dakota's practice to use 1000 lb/ft^2 to account for various loads (passive pressure, thermal, creep and shrinkage loads) and Iowa's use of the a simple, fixed-head pile model which does not consider passive or active pressure and is based on research conducted by Greimann and Abendroth at Iowa State University during the 1980s.

Foundations

The monolithic construction of the deck with integral abutment (backwall) requires special design for the backwall and supporting piles of integral abutments and jointless bridges. The design of the foundation for integral abutments needs to account for the expansion and contraction of the bridge due to thermal movement. The resulting soil pressures due to thermal expansion and restraining effects due to jointless construction of the bridge have been recognized as the controlling load for design of integral abutments and piles. Designing and detailing of integral abutments to handle these forces is critical for the proper performance of integral abutments.

The 2004 IAJB survey questions where chosen to obtain an understanding about how states are designing foundations for integral abutments, including criteria used to select foundation type, type of pile, orientation of pile, pile design considerations, pressure used in the design of integral abutments and special details utilized to reduce the pressures at the integral abutment.

The survey indicate that full- integral abutment with steel bearing piles is the most commonly type of integral abutments (~ 70%). However, several states noted that they are currently designing and/or creating standards for semi-integral abutments. The comments provided indicated that semi-integral abutments are commonly used with the uncharacteristic designs that incorporate larger skews, higher abutment walls and unique soil conditions.

The use of deck extensions is predominant in the northeast region as is evident in the large number of in-service deck extensions in this region.

Some States indicated that in addition to steel bearing piles (H piles and pipe piles), friction piles and spread footings, they are using drilled shafts for foundations of integral abutments. Noteworthy, even though steel bearing piles were the most common type of pile used for integral abutments, there was no consensus on the typical orientation of the pile. Thirty three percent (33%) of the responding states orient the piles with the strong axis parallel to the centerline of bearing, 46% orient the piles with the weak axis parallel to the centerline of bearing, 8% (3 states) leave it to the discretion of the Engineer and the remaining 13% did not provide a comment or noted that the question was not applicable because of their use of symmetric piles. The non-uniformity of pile orientation seems to indicate that this is an area where further standardization is warranted.

There are a number of states have developed 'office practices' that allow designers to detail integral abutments without doing complicated analysis. These states use the office practices in conjunction with geotechnical recommendations based on soil parameters to decide the type of foundation used. Based on the comments provided, there is no evidence of problems relating to the type of foundation used for integral abutments.

The use of MSE wall has increased dramatically over the years and as such the use of integral abutments where the MSE walls serves as a component of the integral abutments has increased correspondingly. Based on the survey responses, the preferred detail is to offset the MSE wall from the integral abutment and footing between two feet to five feet.

The soil pressure used for the design of integral abutments and its piles has been the subject of controversy and much research. The majority of the respondents indicated that they use passive pressure (33%) and/or a combination of passive and active pressures (18%). Active pressures, however, is used by a minority of respondents (8%) and other combination of pressure and/or methods was used by 26% of the states responding. The survey was not specific enough to make any conclusions about the variability of pressures used in the design of integral abutments.

Approach Slabs

Some of the most common problems associated with integral abutments are the settlement and the cracking of approach slabs. Fortunately, these problems do not cause a significant disruption of traffic or a decrease of the service life of the bridge.

Thirty-one percent (31%) of respondents indicated that they use a sleeper pad at the end of approach slab, 26% indicated that they float the slab on the approach fills and 30% indicated that they do both.

Many states indicated that they have or are using corbels on the abutment backwall for the support of the approach slab, while other states indicated that they use reinforcing projecting from the abutment backwall to tie the approach slab to the abutment backwall, and other states are using a combination. Based on the responses received, it is evident that the detailing of approach slabs, including the connection to the abutment backwall and the interface between the approach slab and approach fills is an area where standardization and guidelines would be beneficial.

Survey indicates that approach slab settlement, cracking, and bump at the interface between the approach slab and approach fill are the major problems with approach slabs.

In order to mitigate some of the problems with approach slabs, several states are using buried approach slabs and/or select fills under the approach slab while other states have filled voids under approach slab with grout, resurfaced approach slabs with asphalt, and/or used an overlay. Surprisingly, a state noted that the reasons they do not use integral abutment bridges anymore are because of the bump formed at the end of the approach slab and settlement problems under approach slabs due to poor drainage.

MITIGATION MEASURES FOR APPROACH SETTLEMENTS

Based on the literature review conducted, it is apparent that no single factor is responsible for approach fill settlement. Several factors contribute. Remedial measures need to be taken to eliminate or mitigate these factors. The most significant factors are the following:

1. Settlement of the approach fill, which can be large when compaction and drainage are poor,
2. Settlement of the foundation that supports the approach fill, which can be large when the foundation soil is soft and compressible,
3. Other factors such as pavement growth and severe traffic loading.

A report prepared for the West Virginia Transportation Department by Bennett et al. (1996) provides a useful discussion about the causes o f approach fill settlement, and short-term and long-term remedial actions. Based on this report and other studies, the following measures have been found to be effective in preventing and mitigating approach settlement problem.

- Settlements should receive prime attention during design. Settlement analysis should be performed to estimate settlements of the bridge and its approaches. In order to achieve this, sufficient geotechnical data should be obtained.
- An efficient drainage system should be incorporated in the design. In general, keeping the water away from the soil is a simple yet significant factor in reducing the settlement ofthe soil.
- Adequate compaction specifications and procedures should be employed. The denser the soil, the less vulnerable it is for settlement. One exception to this is the soil within the close proximity o f the abutment. The cyclic nature o f the abutment movement will loosen dense backfill and densify the loose backfill. In other words, deformations induced by the abutment results in a density that is independent ofthe initial density ofthe backfill material. Therefore, using very dense backfill is not likely to help reduce settlement associated with moving abutments. This should be recognized and either approach slabs with sleeper slabs, or continuous pavement patching is required to compensate for the inevitable approach fill settlements.
- If the foundation soil is likely to settle significantly, soil improvement such as preloading, vertical drains, and other stabilization techniques should be considered. Removal and replacement of the unsuitable material may be a viable alternative. To reduce the loads on the foundation soil, the embankment can be constructed o f lightweight materials.
- It should be recognized that integral bridges require continuous, yet reduced, maintenance. Depending on the circumstances, the maintenance comprises asphalt overlays, slab jacking, and approach slab adjustment or replacement.

CONCLUDING REAMRKS and RECOMMENDATIONS

Integral abutment bridges perform well with fewer maintenance problems than conventional bridges. Without joints in the bridge deck, the usual damage to the girders and piers caused by water and contaminants from the roadway is not observed.

1. With jointless bridges, all of the movement due to temperature changes takes place at the abutments and this approach system area requires special attention to avoid development of a severe "bump at the end of the bridge." Finite element analyses show that the zone o f surface deformation extends from the back o f the abutment a distance equal to about three to four times the height ofthe abutment.
2. The movement of the abutment into the approach fill develops passive earth pressure that is displacement-dependent. Using full passive pressure regardless of displacement is not conservative because it reduces the flexural effects of dead and live load in the bridge girders.
3. The ground around the piles moves along with the movement of the abutment. The

relative movement between the pile and ground is therefore reduced, resulting in relatively low shear forces at the top of the pile.

4. The total lateral movement o f the top o f the pile relative to the end embedded in the ground is important because it reduces the axial load capacity of the pile. This lateral movement is one of the key variables in assessing the maximum design length of integral abutment bridges. The cyclic nature of these movements raises concern about the vulnerability of piles to cyclic loading.
5. Settlement of the approach fill will occur with time. Using a properly compacted well-drained backfill can mitigate it, but it cannot be eliminated.

Recommendations Design Detail from Practice (Mistry)

- Use embankment and stub-type abutments.
- Use single row of flexible piles and orient piles for weak axis bending.
- Use steel piles for maximum ductility and durability.
- Embed piles at least two pile sizes into the pile cap to achieve pile fixedly to abutment.
- Provide abutment stem wide enough to allow for some misalignment of piles.
- Provide an earth bench near superstructure to minimize abutment depth and wingwall lengths.
- Provide minimum penetration of abutment into embankment.
- Make wingwalls as small as practicable to minimize the amount of structure and earth that have to move with the abutment during thermal expansion of the deck.
- For shallow superstructures, use cantilevered turn-back wingwalls (parallel to center line of roadway) instead of transverse wingwalls.
- Provide loose backfill beneath cantilevered wingwalls.
- Provide well-drained granular backfill to accommodate the imposed expansion and contraction.
- Provide under-drains under and around abutment and around wingwalls.
- Encase stringers completely by end-diaphragm concrete.
- Paint ends of girders.
- Caulk interface between beam and backwall.
- Provide holes in steel beam-ends to thread through longitudinal abutment reinforcement.
- Provide temporary support bolts anchored into the pile cap to support beams in lieu of cast bridge seats.
- Tie approach slabs to abutments with hinge type reinforcing.
- Use generous shrinkage reinforcement in the deck slab above theabutment
- Pile length should not be less than 10 ft. to provide sufficient flexibility.
- Provide prebored holes to a depth of 10 feet for piles if necessary for dense and/or cohesive soils to allow for flexing as the superstructure translates.
- Provide pavement joints to allow bridge cyclic movements and pavement growth.
- Focus on entire bridge and not just its abutments.
- Provide symmetry on integral bridges to minimize potential longitudinal forces on piers and to equalize longitudinal pressure on abutments.
- Provide two layers of polyethylene sheets or a fabric under the approach slab to

minimize friction against horizontal movement.

- Limit use of integral abutment to bridges with skew less than 30 degree to minimize the magnitude and lateral eccentricity of potential longitudinal forces.

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